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NORMAL STAGES IN THE DEVELOPMENT OF THE LARVAE OF *RANA TIGRINA* DAUD. AND *BUFO ANDERSONII* BOULENG.

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Introduction

While engaged in studying the development of the pectoral girdle of *Rana tigrina* Daud. and of Bufo andersonii Bouleng., the author found that the normal stages of the development of the larvae of these anurans have not hitherto been described in sufficient detail. Paucity of information, therefore, hindered the progress of the main work in hand. Therefore, the stages of the larvae of these forms (*Rana tigrina* and *Bufo andersonii*) were first determined and are being described in the present paper.

Before 1946, when Taylor and Kollros described in detail the normal stages of the larvae of *Rana pipiens*, some workers had described stages of the tadpoles of several anurans, for instance Wintrebert (1905) in the case of *Rana temporaria* and *R. viridis*, Tschernoff (1907) in *R. ovalis* (*Rana temporaria*), Emmett and Allen (1907) in *R. pipiens*, Schreiber (1937) in *Bufo vulgaris* and Eakin and Harris (1945) in *Hyla*. Most of them distinguished the several stages either on the basis of the length of the body or the ratio of the length of the tail to that of the body. But these characters are extremely variable and therefore unreliable, as also pointed out Taylor and Kollros (1946), "Since, in amphibians generally, individuals at the same level of morphological development may vary widely in size, due to different conditions of feeding or temperature, and also since significant morphological changes often occur with but slight accompanying changes in absolute or relative measurements of body parts, criteria based on size alone prove inadequate." With this fact in view, the stages of the larvae of *Rana tigrina* and *Bufo andersonii* described here are based mainly on the morphological characters and the age, even pigmentation and colour have not been taken into account as they also were found to vary considerably.

Material and Technique

The material for the present study consisted of tadpoles of *Rana tigrina* Daud. and *Bufo andersonii* Bouleng., which were graded into *twelve* successive stages (*vide infra*). The stages were collected from about a dozen adult individuals of both sexes that were kept in a tank and allowed to breed. The fertilized eggs were transferred to a number of glass aquaria (4′×2′×1′·6″) in which they developed.

Starting with stage 20 of Pollister and Moore (1937) a number of tadpoles were taken out, every twelve hours, killed and preserved in 70 per cent alcohol.

NUMBERING OF STAGES

In numbering the stages of the larvae of *Rana tigrina* and *Bufo andersonii* Taylor and Kollros (1946) were followed. They numbered the stages of the larvae of *Rana pipiens* by Roman numerals in order to distinguish them from the embryonic stages which Shumway (1940, 1942) numbered by Arabic numerals. Thus if we were to consider the entire development of *R. pipiens*, embryonic and larval, Taylor and Kollros' stage I would actually mean the 26th stage of the development as it follows the 25th embryonic stage described by Shumway. However, this kind of gradation will not hold good in the case of *Rana tigrina* and *Bufo andersonii*, because in them, like the larval period the embryonic periods are also completed in a comparatively shorter period of time, so that all the twentyfive embryonic stages described by Shumway, in the case of *R. pipiens*, are not distinctly defined in the Indian species.

THE DEVELOPMENTAL STAGES

According to Taylor and Kollros (1946), the larval period in *Rana pipiens* extends over 85-90 days. They described 25 stages of the larvae of this species and grouped them into (a) *Limb bud stages* (b) *Paddle stages*, (c) *Foot stages*, and (d) *Metamorphic stages*, containing *five*, *five*, *seven* and *eight* stages respectively. However, in *Rana tigrina* and *Bufo andersonii* the larval period lasts only up to 20 and 15 days respectively. In each case, only 12 stages of the larvae are defined which are grouped into (a) *Limb bud*, (b) *Paddle*, (c) *Foot*, (d) *Three-legged* and (e) *Metamorphic* phases containing *one*, *two*, *three*, *one*, and *five* stages respectively. The occurrence of only twelve larval stages in *R. tigrina* and *B. andersonii*, as compared to twentyfive of *R. pipiens*, is perhaps due to a faster rate of changes in the former species.

DESCRIPTION OF THE STAGES

1. *Limb-bud Phase*

According to Taylor and Kollros (1948), the limb-bud appears in *R. pipiens* "one week after the beginning of feeding", but in *Rana tigrina* and *Bufo andersonii*, they not only appear with the onset of feeding but also grow very fast so that by the time the onset of feeding is detected by the presence of particles in the gut, they are practically as long as their diameter. Therefore, in *Rana tigrina* and *Bufo andersonii*, a single stage (Stage I), corresponding to the five stages reported in *R. pipiens* (Taylor and Kollros), occurs.

Stage I (Limb-bud Stage)—The buds of the hind limbs project backwards as blunt stumps and are as long as or longer than their diameter; horny jaws are present; opercular folds grow back over the external gills; gut coiled and situated mainly towards the left side of the body; and tail piece present.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	10-14	9-11
Length of body	4-6	4-5
Length of tail	6-8	5-6
Ratio of length of tail with body	1·50-1·33	1·25-1·20

2. *Paddle Phase*

Taylor and Kollros (1946) described five paddle stages in the case of *Rana pipiens*. In the first (stage VI), "the distal end of the hind limb is flattened medio-laterally to form the foot-paddle; there are no inter-digital indications of the paddle margin", while the remaining four (VII, VIII, IX, X) stages are differentiated on the basis of indentation between the toes which appear one by one; the indentation between the fifth and the fourth toes appear first, followed by those between the fourth and the third; the third and the second and the second and the first toes. However, in *Rana tigrina* and *Bufo andersonii*, although the first stage of this group (Stage II) compares with that (Stage VI) in *Rana pipiens*, the indentations between all the toes appear simultaneously, so that a single stage (Stage III) of *R. tigrina* corresponds to the stages VII, VIII, IX, and X of *R. pipiens* (Taylor and Kollros, 1946).

Stage II (*Paddle Stage*)—Stump of the hind-limb projecting backwards and nearly as long as or more than twice its diameter; its distal end dorso-medially flattened to form a distinct paddle; horny jaws and tail-piece present.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	15-19	11-13
Length of body	6-7	5-6
Length of tail	9-12	6-7
Ratio of length of tail with body	1·83-1·71	1·20-1·16

Stage III (*Inter-digitation Stage*)—Hind limb extends straight back along the side of the body, it shows demarcation into ankle and shank and the margin of the foot-paddle is indented between all the five toes; horny jaws and tail piece present.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	19-26	12-16
Length of body	7-9	5-7
Length of tail	11-12	7-9
Ratio of length of tail with body	1·57-1·33	1·40-1·28

3. *Foot Phase*

Taylor and Kollros (1946) recognise seven stages in this group in *Rana pipiens* based on the gradual appearance and development of the webs and the sub-articular pads in the foot. But in *Rana tigrina* and *Bufo andersonii* changes are rapid, hence only three stages are distinct.

Stage IV (Web-formation Stage)—Hind limb extends almost straightly backwards along the side of the body; it shows distinct demarcation into ankle and shank; foot has all the five toes well differentiated with rudiments of webs between them; horny jaws and tail piece present.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	24-32	15-18
Length of body	8-12	7-8
Length of tail	16-20	8-10
Ratio of length of tail with body	2·00-1·33	1·14-1·25

Stage V (Folded limb Stage)—Hind limb distinctly folded at the joints and demarcated into foot, ankle, shank and thigh; foot well formed, toes with webs present between them; horny jaws and tail piece are present.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	30-38	17-21
Length of body	12-15	7-8
Length of tail	18-28	10-14
Ratio of length of tail with body	1·50-1·53	1·42-1·75

Stage VI (Sub-articular Pad Stage)—Hind limb with distinct foot, ankle, shank and thigh and folded joints; toes with webs between them; sub-articular pads of all the three rows (proximal, middle and distal) present; the phalangeal joints distinct. Horny jaws present but tail piece much reduced; fore-limb well developed covered with a thin skin; "skin window" (Taylor and Kollros, 1946), a transparent disc-shaped area in the wall of the gill chamber, distinct.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	36-42	20-24
Length of body	16-17	8-9
Length of tail	20-25	12-15
Ratio of length of tail with body	1·25-1·47	1·50-1·66

4. *Three Legged Phase*

The author has found that in the tadpoles of *Rana tigrina* and *Bufo andersonii* invariably one of the fore-limbs first projects out of the skin covering the gill chamber. Generally it is the left limb which comes out first, although Taylor and Kollros (1946) speaking about stage XX say that "one or both fore-legs have protruded."

Stage VII (Three-legged Stage)—Hind limb folded; feet, ankle, shank and thigh distinct; the thigh constricted at its proximal end so that it appears to be abutting against the body. One of the fore-limbs, generally the left one, projects out through the opercular fold but the other one, though well developed, is still below it. Horny jaws are present but the tail piece absent.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	40-45	23-26
Length of body	17-18	8-9
Length of tail	23-27	15-17
Ratio of length of tail with body	1·35-1·50	1·87-1·83

5. *Metamorphic Phase*

Taylor and Kollros (1946) include eight stages in this group first three of which (stage XVIII, XIX and XX) are distinguished by the disappearance of the tail piece, clearance of the skin window and emergence of either one or both of the fore-limbs. In *Rana tigrina* and *Bufo andersonii,* however, the tail piece appears earlier and the clearance of the skin window and the emergence of one of the fore-limbs, usually the left one, occur rapidly, so that stage XVIII, XIX and XX in *Rana pipiens* correspond to the stage VII (three-legged stage) of the Indian forms.

The remaining five stages of this group (stage XXI, XXII, XXIII, XXIV and XXV) belonging to *Rana pipiens* (Taylor and Kollros 1946) are mainly based on the gradual widening of the gape of the mouth and the reduction of the tail. The metamorphic stages (VIII, IX, X, XI and XII) in *Rana tigrina* and *Bufo andersonii* are also based mainly on these characters and correspond proximately with their counterparts in *Rana pipiens.*

Stage VIII (*Limb Stage*)—Both the fore-limbs emerged out of the opercular cavity; horny jaws present, tail piece absent and the tail much longer than the hind limbs.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	41—46	24—26
Length of body	17—18	8—9
Length of tail	24—28	16—17
Ratio of length of tail with body	1·41—1·55	2·00—1·88

Stage IX (*Mouth Stage*)—Horny jaws absent; the gape of the mouth extends to a middle point between the nostril and the anterior margin of the eye or up to the anterior margin of the eye. Dorsal and ventral tail fins shrunken, tail reduced in length, being equal to or slightly longer than the extended hind limb and all four limbs well developed.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	36—40	18—22
Length of body	17—18	9
Length of tail	19—22	9—13
Ratio of length of tail with body	1·11—1·33	1·00—1.44

Stage X (*Short-tail Stage*)—Gape of the mouth wide, the angle of the mouth extending up to the middle of the eye. Tail fins practically absent and the tail distinctly shorter than the extended hind limb.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	28—35	15—17
Length of body	18—19	9
Length of tail	10—16	6—8
Ratio of length of tail with body	0·55—0·84	0·66—0·88

Stage XI (*Tail-stub Stage*)—Tail reduced to a stub, gape of the mouth very large, the angle of the mouth extending up to the hinder margin of the eye.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Total length	22—27	10—14
Length of body	18—19	8—9
Length of tail	4—8	2—5
Ratio of length of tail with body	0·22—0·42	0·25—0·55

Stage XII (*Adult Stage, Young*)—Tail lost; angle of the mouth extends beyond the hinder border of the eye; limbs stout.

Measurements in mm.	*Rana tigrina*	*Bufo andersonii*
Length of body	18—19	8—9

SUMMARY

The author has extended Shumway's (1940) work by describing *twelve* larval (tadpole stages) in *Rana tigrina* Daud. and *Bufo andersonii* Bouleng., basing them mainly on the morphological characters. The stages recognised on age group basis constitute essentially an arbitrary series. Therefore, the total development is comprised in a series of periods, each extending from one stage to the next. In general practice the points and periods are not sharply demarcated and it is convenient to describe each period in terms of stages that indicates it.

The larval period in *Rana tigrina* Daud. and *Bufo andersonii* Bouleng. is very short and extends up to only 20 and 15 days respectively.

Twelve stages of the larvae are described in each species which are grouped into five phases marked by the (a) *limb-bud*, (b) *foot-paddle*, (c) *foot*, (d) *three leggedness* and (e) *metamorphosis*.

The *limb-buds* appear almost simultaneously with the on set of feeding and grow very fast.

In the stages of the *paddle phase* the distal end of the limb-bud is flattened medio-dorsally, on the margin of which interdigital indentations between all the toes appear almost simultaneously. The paddle phase comprises of *paddle stages* and the *inter-digitation stages*.

The *foot phase* is based on the appearance and development of webs and sub-articular pads in which (a) *web formation stage* (b) *folded limb stage* and (c) *sub-articular pad stage* can be made out.

The *three-legged phase* which has not been regarded as a distinct stage in *Rana pipiens* by Taylor and Kollros (1946) has been mentioned in *Rana tigrina* and *Bufo andersonii.*

The *metamorphic phase* is based on the gradual widening of the gape of the mouth and reduction of the tail, and includes *five* stages: (a) *limb-stage,* (b) *mouth stage,* (c) *short-tail stage,* (d) *tail-stub stage* and (e) *adult stage* (young).

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I am extremely grateful to Dr. B. C. Mahendra and Dr. Surendra Sharma for their painstaking guidance and help in the present work. I am also grateful to Dr. C. P. Singh, Professor of Zoology, Agra College, Agra, for providing me with necessary laboratory facilities, and for a great deal of encouragement and interest.

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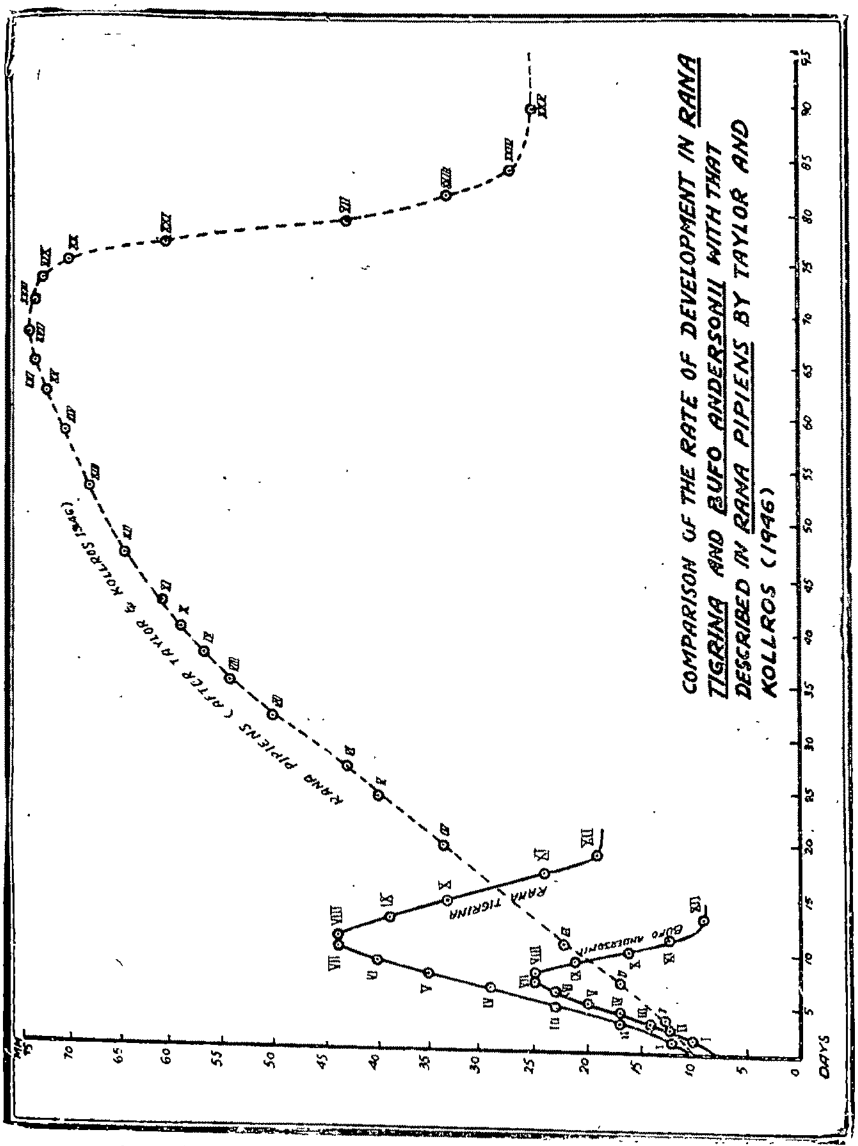

Fig. 1. Comparison of the rate of development of *Rana tigrina* and *Bufo andersonii* with that described in the case of *Rana pipiens* by Taylor and Kollros (1946).

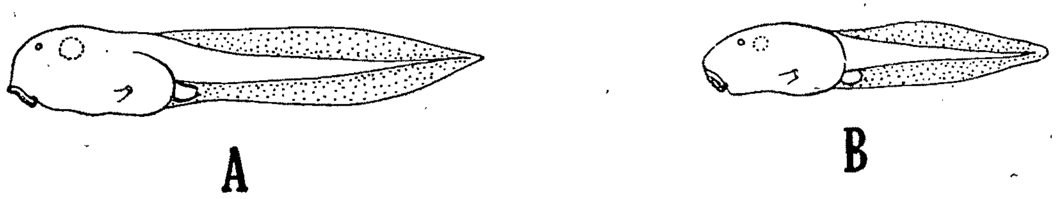

Fig. 2. Limb-bud Stage. A—*Rana tigrina*; B—*Bufo andrsonii.*

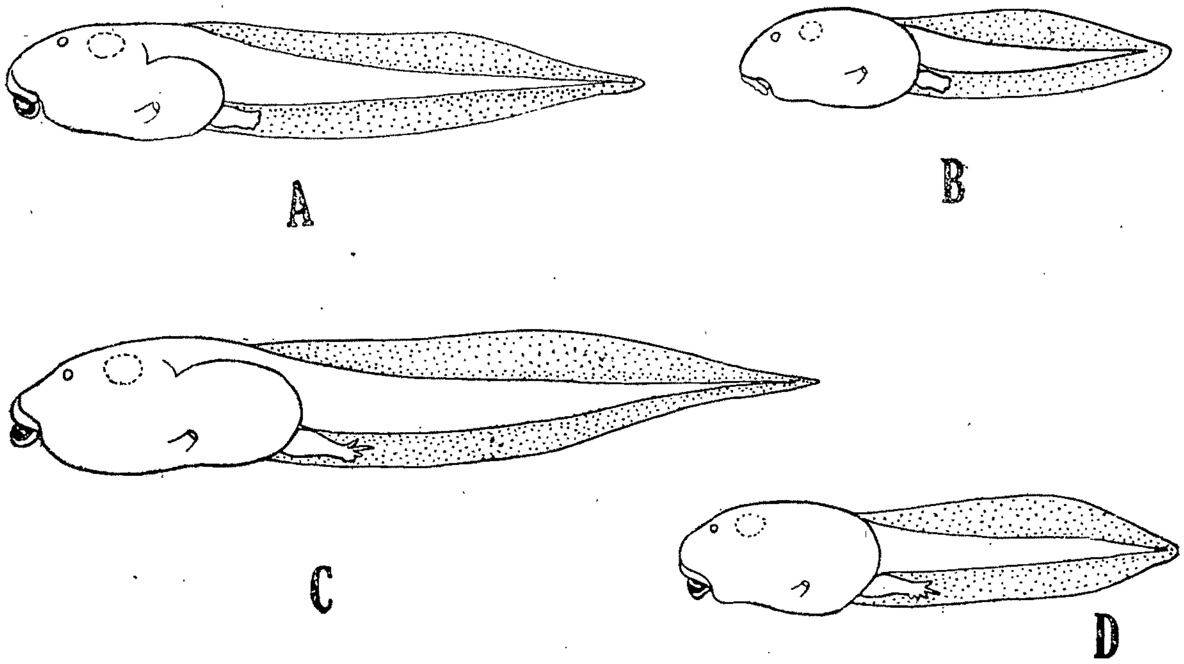

Fig. 3. Paddle Phase. A and B—Paddle Stage; C and D—Inter-digitation Stage. Figs. A and C of *Rana tigrina* and B and D of *Bufo andersonti.*

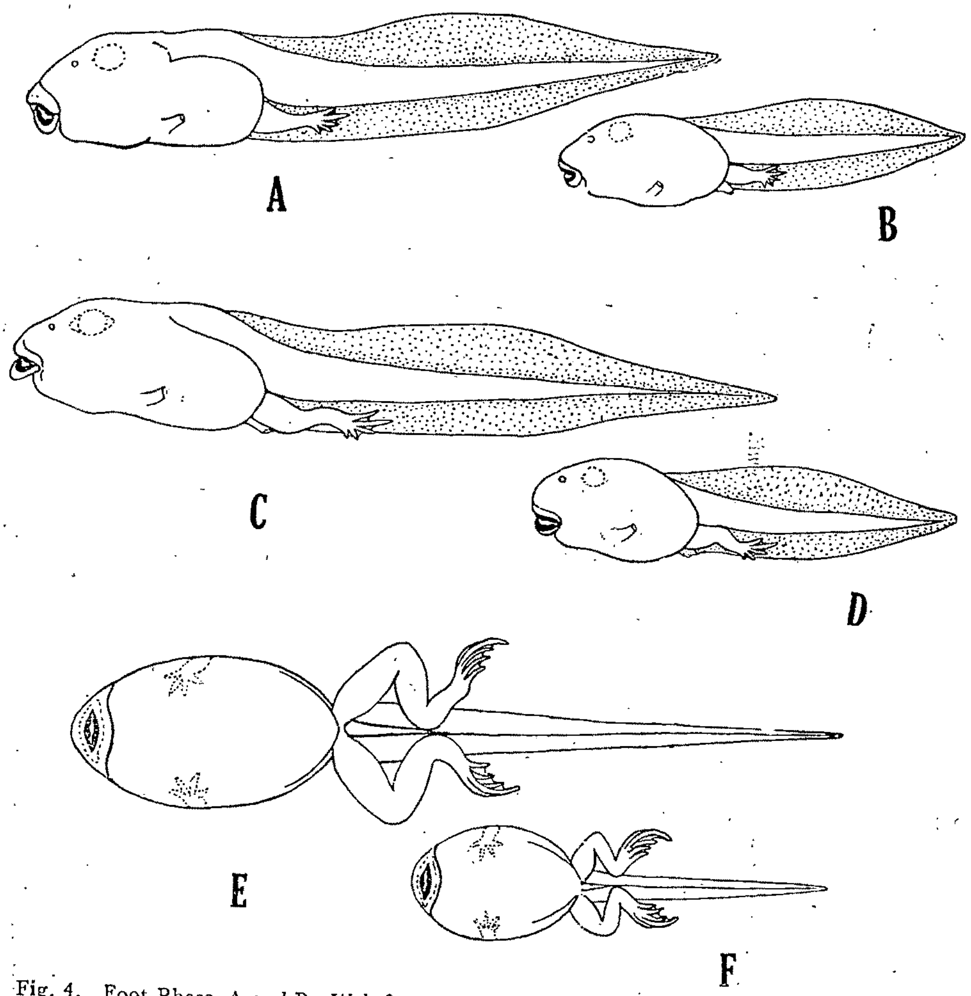

Fig. 4. Foot Phase. A and B—Web-formation Stage; C and D—Folded limb Stage; E and F—Sub-articular Pad Stage. A, C and E belong to *Rana tigrina*; B, D and F to *Bufo andersonii*.

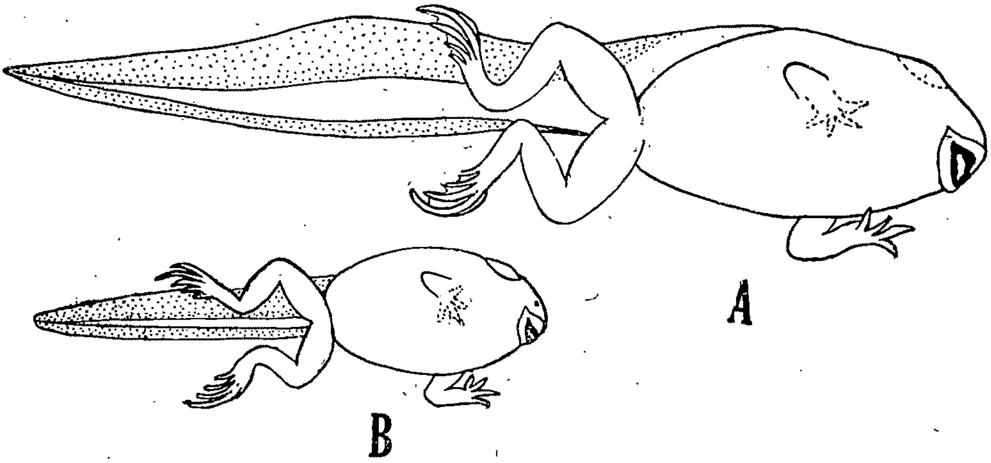

Fig. 5. Three legged Stage. A—*Rana tigrina;* B—*Bufo andersonii.*

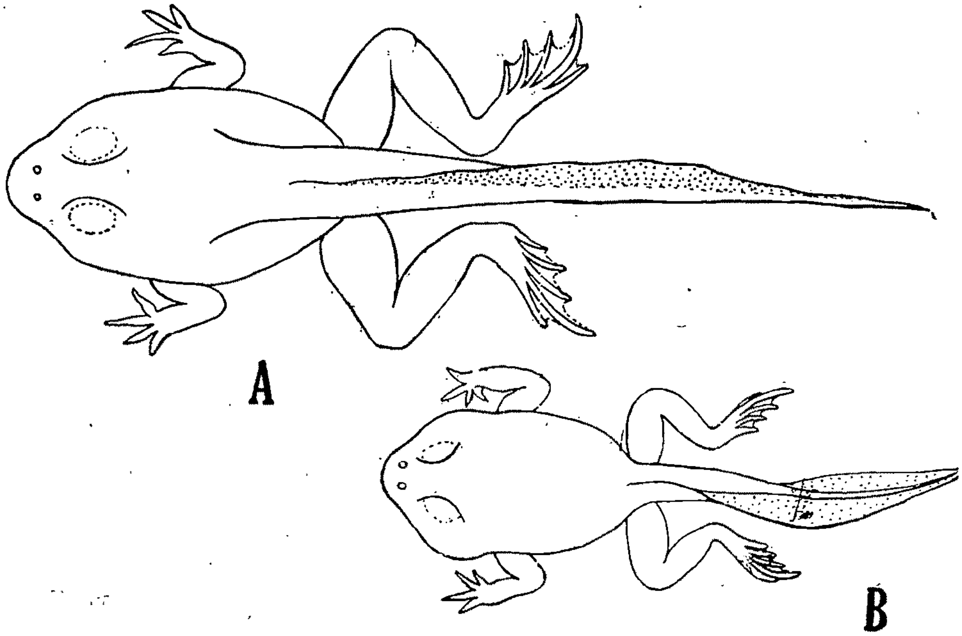

Fig. 6. Metamorphic Phase (Limb Stage). A—*Rana tigrina;* B—*Bufo andersonii.*

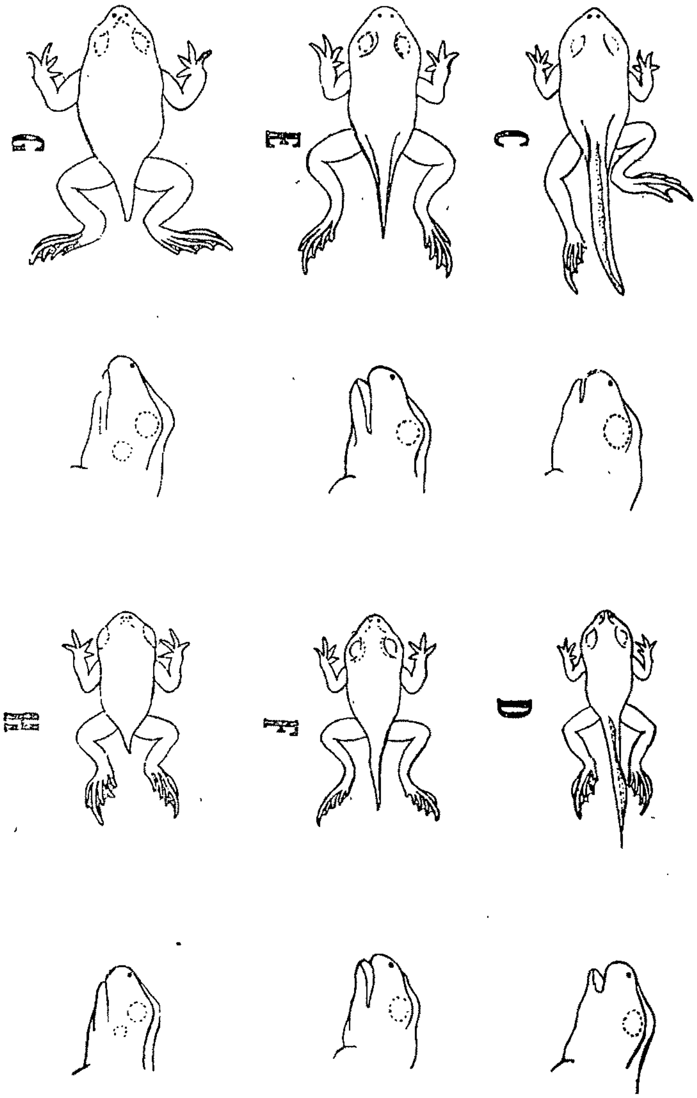

Fig. 7. Metamorphic Phase. C and D—Mouth Stage; E and F—Short tail Stage; G and H Tail-stub Stage. C. E and G of *Rana tigrina*; D, F and H of *Bufo andersonii*.

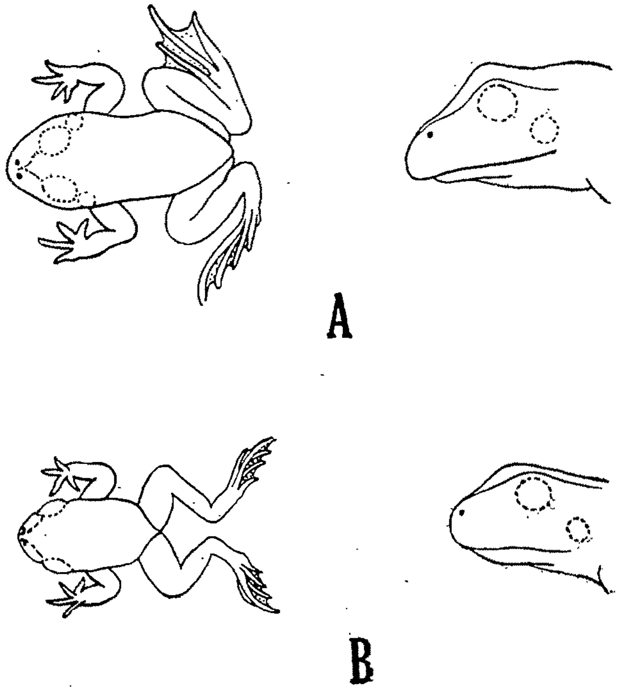

Fig. 8. Adult Stage. A—*Rana tigrina*; B—*Bufo andersonii*.

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FOOD, FEEDING HABITS AND THE ALIMENTARY CANAL OF FRESH WATER FISHES OF MUZAFFARNAGAR

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At present no authentic account of the fish fauna of Muzaffarnagar and its neighbourhood is available. As a matter of fact the whole of Muzaffarnagar and Saharanpur area offers a virgin field for scientific survey of its fish fauna and fisheries. During the general survey of the fish fauna of the district s many as 60 species were collected.

The district Muzaffarnagar is situated towards the north-west of Uttar Pradesh the mean latitude and longitude being 29° and 77°. It extends for about 52 miles east to west and about 30 miles north to south. The district has rich water resources having as many as 9 rivers, such as Burhi Ganga, Solani, Kalinadi, Krishna, Hindon, Ganges and Jamuna. Besides, there are a few canals and quite a few lakes and ponds of permanent nature. The average annual rainfall varies between 20″ to 40″ (Fig. 1).

One of the important problems of fishery is the investigation of the nutrition of fishes in order to understand the qualitative and quantitative connection between them and their food. This provides valuable data not only for the determination of food chains but also about the shoaling and migratory habits of fishes, thus foretelling the prospects for commercial fisheries.

Not much is known about the food of Indian fresh water fishes. Mukerjee et al (1947) and Chacko and Kuriyan (1948) studied the food of the fishes of Bengal and Madras respectively while Chacko (1949) investigated the food and feeding habits of a few marine fishes. Moitra (1956) has studied the food habits of certain fishes of Lucknow.

In the present paper 58 species of fresh water fishes of economic importance have been studied. Their feeding habits have been studied by examining the gut contents of freshly collected fishes. The standard length of the fish has been taken into consideration. The average size of the alimentary canal in these fishes has also been determined so as to correlate the effect of diet on the size of the alimentary canal.

OBSERVATIONS

Family, **Clupeidae**

Gadusia chapra (Ham.)

It is mainly herbivorous in habit. The food of the fish consists of algae, aquatic plants and sand particles. Rotifers have also been recorded.

Gadusia has a very long alimentary canal. In a fish, about 82 mm. long, the length of the alimentary canal is about 380 mm. It has numerous caeca arising from the anterior part of the intestine.

Family, **Notopteridae**

Notopterus chitala (Ham.)

N. chitala forms an important food fish of the locality. It is mainly carnivorous in habit, feeding on insects, insect larvae and planktonic Crustacea. In a few cases aquatic plants have also been found within the gut of the fish.

The length of the alimentary canal is comparatively small. In a fish of the standard length 810 mm., the alimentary canal is found to be about 590 mm. It has a pair of pyloric caeca arising from the anterior end of the intestine and a single rectal caecum, arising at the junction of intestine and rectum.

Notopterus notopterus (Pallas)

It is also mainly carnivorous in habit and has a small alimentary canal being 117 mm. long in a fish of 230 mm. standard length.

Family, **Cyprinidae**

Chela bacaila (Ham.)

The fish *Chela bacaila* is predominantly herbivorous in habit. The food of the fish consists of small aquatic plants and algal filaments.

The alimentary canal of the fish is large i.e. in a fish of about 105 mm. length, the gut was about 120 mm.

Chela labuca (Ham.)

It is omnivorous in its feeding habit. Its food consists of small Crustacea and aquatic plants.

The length of the alimentary canal of a fish of about 105 mm. length is found to be 120 mm.

Barilius bola (Ham.)

B. bola forms a food fish of economic importance. It is predacious and carnivorous. The alimentary canal is found to contain small fishes on which it feeds.

The alimentary canal is comparatively small, in a fish of 205 mm. length, the alimentary canal is only 203 mm.

Barilius bendelisis var. chedra (Ham.)

It is predominantly herbivorous; its gut contents include algal filaments, aquatic plants and Euglinae.

The alimentary canal of the fish is very long. In a fish of about 120 mm. lenght, the alimeary canal is as long as 770 mm.

Barilius barna (Ham.)

Barilius barna is omnivorous. Its food consists of small worms and algal filaments.

The alimentary canal of a fish, about 44 mm. long, is found to be about 53 mm. in length.

Barbus chagunio (Ham.)

The fish is commonly eaten by local people. It is carnivorous, feeding mainly on Crustacea, insects and small fishes.

The alimentary canal is comparatively small. In a fish of 120 mm. standard length, the alimentary canal is found to be 107 mm.

Barbus (*Tor*) *tor* (Ham.)

The fish is of economic importance and easily available. It is herbivorous in habit, feeding mainly on algal filaments and small aquatic plants.

The alimentary canal is quite long, in a fish of 175 mm. length, the gut is 319 mm.

Puntius sophore (Ham.)

The fish is an omnivorous feeder. The major part of its diet is composed of diatoms, filamentous algae and tender roots and leaves of aquatic plants. Rotifers and crustaceans have also been found in the gut contents. In rare cases, aquatic mites and insect larvae have also been found.

The alimentary canal is fairly large. In an animal, about 60 mm. long, the length of the gut is 240 mm.

Puntius sarana (Ham.)

Puntius sarana feeds on diatoms, filamentous algae and tender parts of small aquatic plants. According to Moitra (1956) it has been found to feed on bryozoans and molluscs also. The observations of the present authors, however, agree with those of Mookerjee et al (1947) in Calcutta and of Chacko and Kuriyan (1948) in Madras.

The size of the alimentary canal as could be expected in a herbivorous fish, is fairly long i.e. in a specimen of about 60 mm. length, the gut is more than 100 mm. long.

Puntius ticto (Ham.)

It is also herbivorous in habit, feeding mainly on the algal filaments and small aquatic plants. The alimentary canal of a fish of 188 mm. length, is about 430 mm. long.

Crossocheilus latia (Ham.)

It is predominantly herbivorous with a very long alimentary canal. In a fish of about 90 mm. length, the gut was found to be about 708 mm. long.

Rohtee cotio (Ham.)

Rohtee cotio is herbivorous and feeds mainly on algal filaments and aquatic plants. The alimentary canal of a fish of 75 mm. length, was found to be about 97 mm. long.

Esomus danricus (Ham.)

The fish is herbivorous in habit, the gut contents consist of the algal filaments, pieces of aquatic plants and sand particles.

The alimentary canal is very long and in a fish of 210 mm. length it is more than 3000 mm. long.

Cirrhina reba (Ham.)

It is a fish of great economic importance. It is herbivorous.

The length of the alimentary canal in a fish of about 134 mm. length is found to be about 202 mm. The gut of the fish presents a beaded appearance and probably each bead represents a morsal of food taken by the fish.

Cirrhina mrigala (Ham.)

It is herbivorous in habit; the stomach is found to be full of algal filaments and sand particles.

The alimentary canal is very long and in a fish about 280 mm. length, it is 4018 mm.

Garra gotyla (Gray)

It is rather rare in this locality and is adapted to hill streams. It is herbivorous and the gut contains algal filaments and sand particles.

The alimentary canal is very long; in a fish of about 113 mm. length, the gut is as long as 1110 mm.

Catla catla (Ham.)

It is a fish of great economic importance and is exported to the different parts of the country. It is herbivorous in habit. However, in addition to algae and other aquatic plant material, some Crustacea have also been observed in its stomach.

The alimentary canal is very long being about 4175 mm. in a fish of 355 mm. length.

Labeo rohita (Ham.)

This fish is also of great economic importance and is exported to places like Calcutta. It is also herbivorous and the gut contents of the fish consist of the aquatic plants, algal filaments and sand particles.

The alimentary canal of a fish of 355 mm. length, is found to be 4175 mm. long.

Labeo calbasu (Ham.)

Like the preceding two, this is also a fish of great economic importance. It is also exported to other places and is herbivorous. The gut is found full of algal filaments and sand particles.

The alimentary canal is very long. In a fish, about 237 mm. length, the gut is 4152 mm. long

Labeo gonius (Ham.)

It is also of economic importance and is herbivorous. The alimentary canal is very long i. e. in a fish of 194 mm. length, the gut is 2280 mm. long.

Labeo dero (Ham.)

Labeo dero is also taken as food. It is herbivorous and feeds on aquatic plants. In a fish of 105 mm. length, the alimentary canal is 1152 mm. long.

Labeo bata (Ham.)

It is also used as food and is herbivorous. The gut contents consist of the algal filaments and sand particles.

The alimentary canal of a fish of 131 mm. length, is found to be 366 mm. long.

Family, **Cobitidae**

Nemachilus botia (Ham.)

The fish is carnivorous. The gut contents include small copepods and other small Crustacea as well as some insect larvae.

The alimentary canal of the fish is of average size, being about 94 mm. long in a fish of 67 mm. length.

Botia lohachata (Chaudhuri)

It is eaten by people of low income group. It is a carnivorous fish, feeding on small Crustacea and crustacean larvae.

The alimentary canal is of average size; in a fish, about 86 mm. long, the length of the gut is 133 mm.

Family, **Siluridae**

Wallago attu (Bl. & Schn.)

Wallago attu is a fish of great economic importance. It is predominantly carnivorous in habit feeding on small fishes and crustaceans. The alimentary canal is comparatively small. In a fish of 188 mm. length, the alimentary canal is 102 mm. long.

Ompok bimaculatus (Bloch)

It is also sometimes called as *Callichrous*, the name proposed by Hamilton in 1822. However, the name *Ompok* was established earlier by Lacepede in 1803 and is the valid genus.

The fish is predatory in nature and feeds on small Crustacea. The alimentary canal of a fish of 166 mm. length is 234 mm. long.

Ailia coilia (Ham.)

It is a small fish and is mainly carnivorous. In a fish of about 110 mm. length, the gut is found to be 74 mm. long.

Family, **Bagaridae**

Mystus (Osteobergus) seenghala (Sykes).

The fish is also known as *Macrones*. Their abundance and low price are responsible for their demand and consumption. It is omnivorous and the gut contents include small worms, aquatic plants and sand particles.

It is found that the alimentary canal of a fish of about 136 mm. length, is 167 mm. long.

Mystus cavasius (Ham.)

It is also omnivorous and the gut contents include algal filaments and insect larvae. The length of the alimentary canal of a fish of about 115 mm. length, is found to be 185 mm.

Mystus vittatus (Bloch)

Mystus vittatus is omnivorous in habit and feeds on insect larvae and algal filaments. The alimentary canal is of almost the same size as the size of the fish.

Mystus cor (Ham.)

It is also omnivorous and feeds on worms and tender parts of the aquatic plants. The alimentary canal is quite small being about 158 mm., in a fish of 143 mm. length.

Rita rita (Ham.)

It is a carnivorous fish feeding mainly on small Crustacea. The alimentary canal of a fish of 120 mm. length, is found to be 173 mm. long.

Family, **Sisoridae**

Sisor rhabdophorus (Ham.)

It is mainly carnivorous, the gut contents consisting of Crustacea and small worms.

The alimentary canal is comparatively small being about 134 mm. long in a fish of about 130 mm. length.

Bagarius bagarius (Ham.)

Bagarius bagarius is an omnivorous fish; its stomach is usually found full of small fishes and small plants.

The alimentary canal of a fish of 123 mm. length, is about 180 mm. long.

Nangara punctata (Day.)

The fish is mainly carnivorous, feeding on large Crustacea and worms. The alimentary canal is of ordinary size, being about 94 mm. long in a fish of 62 mm. tength.

Eutropiichthys vacha (Ham.)

It is a large fish of economic importance. It is a predatory feeder and the stomach is found to contain small fishes. The alimentary canal is comparatively small. In a fish, about 223 mm. long, the length of the gut is 210 mm.

Silonia silondia (Ham.)

Silonia silondia is carnivorous and feeds on small fishes, Crustacea, Mollusca etc. The alimentary canal of the fish of 510 mm. length, is about 970 mm. long.

Clupisoma garua (Ham.)

It is an omnivorous fish. The food contents include small fishes, Crustacea and occasionally pieces of plants. The alimentary canal is fairly long i.e. in a fish of 117 mm. length, the gut is 515 mm. long.

Family, **Saccobranchidae**

Heteropneustes fossilis (Bloch).

It is important in the live fish trade as it is provided with accessary respiratory organs. It is also known as *Saccobranchus* but as it was named *Heteropneustes* earlier, the name *Heteropneustes* is taken to be the valid term. The fish is carnivorous and feeds on small Crustacea, aquatic insects and insect larvae.

The alimentary canal of a fish, about 120 mm. long, is about 145 mm.

Family **Clariidae**

Clarias batrachus (Linn.)

Clarias batrachus is captured in large numbers from the swamps. It is carnivorous and feeds mainly on small fishes and Crustacea though occasionally, pieces of aquatic plants have also been found in the stomach of the fish.

The length of the gut, in a fish of about 240 mm. length is found to be 210 mm.

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Family, **Belonidae**

Xenentodcn cancila (Ham.)

It is also known as *Belone cancila.* The beak of the fish is greatly elongated. It is a predator, feeding mainly on small fishes, prawns etc.

The alimentary canal of a fish of about 117 mm. length, is about 114 mm. long.

Family, **Mugilidae**

Mugil corsula (Ham.)

Mugil corsula is mainly herbivorous. Its stomach is found to contain algal filaments, aquatic plants, sand particles etc.

The alimentary canal is quite long. In an animal about 185 mm. length, the gut proper is about 500 mm. long.

Mugil cascasia (Ham.)

It is omnivorous and it feeds on aquatic plants and worms. The alimentary canal is of average size. In a fish of about 61 mm. length, the gut is about 114 mm. long.

Family, **Ophicephalidae**

Channa punctatus (Bloch)

It is commonly known as *Ophicephalus punctatus*, the name proposed by Block in 1797. The name *Channa* was given to it by Scopoli in 1777 and is taken to be the valid term. It is a fish of great economic importance. It is mainly carnivorous, feeding on Crustacea, insects etc.

The alimentary canal is quite small. In a fish of about 95 mm. length, the alimentary canal is 66 mm. long.

Channa striatus (Bloch)

Channa striatus is also of great economic importance mainly due to its large size. It is also carnivorus in habit, feeding mainly on Crustacea and worms.

The alimentary canal, in a fish of 129 mm. length, is about 138 mm. long.

Channa gachua (Ham.)

This species of *Channa* is smaller in size; it is also carnivorous feeding on Crustacea, worms etc. In a fish of about 125 mm. length, the gut is about 131 mm. long.

Channa marulius (Ham.)

Channa marulius is very large in size but is of rare occurence. It mainly feeds on small fishes and Crustacea.

The alimentary canal is comparatively small i.e. in a fish of about 144 mm. length, the gut is only 140 mm. long.

Family, **Amphipnoidae**

Amphipnous cuchia (Ham.)

It is an eel-shaped fish living mainly in mud. The local fishermen take it to be a water snake and it is, therefore, not taken as food. It is carnivorous and feeds on worms.

The alimentary canal is quite small; being only 560 mm. long in a fish of 710 mm. length.

Family, **Centropomidae**

Ambassis ranga (Ham.)

It is also carnivorous and feeds on small crustaceans. The alimentary canal of a fish of 30 mm. length, is found to be about 41 mm. long.

Family, **Nandidae**

Nandus nandus (Ham.)

It is small fish with protrusible mouth. It is predominently carnivorous. Its food consists mainly of small fishes and it also shows cannibalistic tendency.

The alimentary canal, of a fish of about 90 mm. length, is about 130 mm. long.

Family, **Anabantidae**

Trichogaster fasciatus (Bl. & Schn.)

It is also known as *Colisa fasciata,* the name proposed by Cuvier and Valenciennes in 1831. It is herbivorous. The food contents consist of algal filaments, diatoms, parts of aquatic plants and sand particles.

The alimentary canal of the fish is very long. In a fish of about 60 mm. length, the gut is found to be about 650 mm. long.

Family, **Gobiidae**

Glossogobius giuris (Ham.)

It is carnivorous. The analysis of the gut contents shows the presence of insects, insect larvae, small bivalves and sometimes plants also. The alimentary canal of a fish of 110 mm. length, is about 105 mm. long.

Family, **Mastacembelidae**

Mastacembelus armatus (Lacep.)

It is a long eel-like fish which feeds mainly on small worms. The alimentary canal is comparatively small i.e. in a fish, about 253 mm. long, the gut is only 183 mm. in length.

Mastacembelus pancalus (Ham.)

It is a small carnivorous fish and feeds mainly on worms and small crustaceans. The gut is comparatively small in length; in a fish about 145 mm. in length, the gut is only 95 mm. long.

Rhynchobdella aculeata (Ham.)

It is also known as *Macrognathus aculeatus*. It is carnivorous and the food contents of the gut include aquatic insects, small Crustacea, worms and sand particles.

The alimentary canal of a fish of about 227 mm. length, is found to be about 195 mm. long.

In the following table (Table 1) is given a brief account of the feeding habits and the ratio between the standard length and the alimentary canal of the fishes studied:

TABLE 1

Th

S. No.	Fishes	Local Name	Feeding habit	Ratio between standard length and alimentary canal
1.	*Gadusia chapra* (Ham.)	Khera	Herbivorous	1:4·4
2.	*Notopterus notopterus* (Pallas)	Patra	Carnivorous	1:0·3
3.	*Notopterus chitala* (Ham.)	Chital	Carnivorous	1:0·73
4.	*Chela bacaila* (Ham.)	Chilwa	Herbivorous	1:1·16
5.	*Chela labuca* (Ham.)	Challa	Carnivorous	1:1·00
6.	*Bcrilius bola* (Ham.)	Gulab	Carnivorous	1:0·99
7.	*Bcrilius bendelisis* Var. Chedra (Ham.)	Anga	Herbivorous	1:6·4
8.	*Barilius barna* (Ham.)	Popla	Herbivorous	1:1·2
9.	*Barbus chagunio* (Ham.)	Chibban	Carnivorous	1 ·0·89
10.	*Barbus* (Tor.) *tor* (Ham.)	Mahasher	Herbivorous	1:1·82
11.	*Puntius sophore* (Ham.)	Bhur	Herbivorous	1:4·03
12.	*Puntius sarana* (Ham.)	Maini	Carnivorous	1:1·55
13.	*Puntius ticto* (Ham.)	Puthiya	Herbivorous	1:2·8
14.	*Crossocheilus latia* (Ham.)	Rurhi	Herbivorous	1:7·95
15.	*Rohtee cotio* (Ham.)	Gurda	Herbivorous	1:1·26
16.	*Esomus danricus* (Ham.)	Moila	Herbivorous	1:14·3
17.	*Cirrhina mrigala* (Ham.)	Mirgal	Herbivorous	1:14·3
18.	*Cirrhina reba* (Ham.)	Rawa	Herbivorous	1:1·42
19.	*Garra gotyla* (Gray.)		Herbivorous	1;9·82
20.	*Catla catla* (Ham.)	Katla	Omnivorous	1:11·7

TABLE 1

S. No.	Fishes	Local Name	Feeding habit	Ratio between standard length and alimentary canal
21.	*Labio rohita* (Ham.)	Rohu	Herbivorous	1:11·2
22.	*Labeo calbasu* (Ham.)	Kalbauns	Herbivorous	1:17·5
23.	*Labio gonius* (Ham.)	Kursa	Herbivorous	1:11·7
24.	*Labio dero* (Ham.)	Bata	Herbivorous	1:11·61
25.	*Labio bata* (Ham.)	Bhangun	Herbivorous	1:2·8
26.	*Nemachilus botia* (Ham.)	Bakatia	Carnivorous	1:1·4
27.	*Botia lohachata* Chaudhuri	Billi	Carnivorous	1:1·54
28.	*Wallago attu* (Bl. & Schn.)	Lanchi	Carnivorous	1:0·54
29.	*Ompok bimaculatus* (Bloch)	Pabda	Carnivorous	1:1·409
30.	*Ailia coilia* (Ham.)	Basmati	Carnivorous	1:0·67
31.	*Mystus (Osteobergus) seenghala* (Sykes)	Singhara	Carnivorous	1:1·23
32.	*Mystus cavasius* (Sykes)	Tingna	Carnivorous	1:1·62
33.	*Mystus vittatus* (Bloch)	Kater	Carnivorous	1:0·94
34.	*Mystus aor* (Ham.)	Tingna	Carnivorous	1:1·1
35.	*Rita rita* (Ham.)	Khagga	Carnivorous	1:1·43
36.	*Sisor rhabdophorus* (Ham.)	Chamla	Carnivorous	1:1·03
37.	*Bagarius bagarius* (Ham.)	Gonch	Omnivorous	1:1·36
38.	*Nangara punctata* Day.	Padna	Carnivorous	1:1·51
39.	*Eutropiichthys vacha* (Ham.)	Charkhi	Carnivorous	1:0·94
40.	*Silonia silondia* (Ham.)	Silond	Carnivorous	1:1·9
41.	*Clupisoma garua* (Ham.)	Bacha	Carnivorous	1:4·4
42.	*Heteropneustes fossilis* (Bloch)	Singhi	Carnivorous	1:1·22
43.	*Clarias batrachus* (Linn.)	Mangur	Carnivorous	1:0·87
44.	*Xenentodon cancila* (Ham.)	Suan	Carnivorous	1:0·98
45.	*Mugil corsula* (Ham.)	Tara	Omnivorous	1:2·76
46.	*Mugil cascasia* (Ham.)	Khaksi	Omnivorous	1:1·87
47.	*Ophicephalus punctatus* (Bloch)	Sauli	Carnivorous	1:0·8
48.	*Ophicephalus striatus* (Bloch)	Kabra saul	Carnivorous	1:1·1

TABLE I

S. No.	Fishes	Local Name	Feeding habit	Ratio between standard length and alimentary canal
49.	*Ophicephalus gachua* (Ham.)	Chinga	Carnivorous	1:1·0
50.	*Ophicephalus marulius* (Ham.)	Guldar saul	Carnivorous	1:0·98
51.	*Amphipnous cuchia* (Ham.)	Andhla sanp	Carnivorous	1:0·79
52.	*Ambassis ranga* (Ham.)	Chandla	Carnivorous	1:1·37
53.	*Nandus nandus* (Ham.)	Bhaidal	Carnivorous	1:1·44
54.	*Trichogaster fasciatus* (Bl. & Schn.)	Kharda	Omnivorous	1:10·07
55.	*Glossogobius giuris* (Ham.)	Gulwa	Carnivorous	1:0·95
56.	*Mastacembelus armatus* (Lacep.)	Bam	Carnivorous	1:0·72
57.	*Mastacembelus pancalus* (Ham.)	Gujbam	Carnivorous	1:0·65
58.	*Rhynchobedella aculeata* (Bloch)	Malga	Carnivorous	1:0·86

DISCUSSION AND SUMMARY

During the study of the fish fauna of Muzaffarnagar district, as many as 60 species, belonging to different families were recorded. The feeding habits of 58 species have been studied and it has been found that although some of the fishes are predominantly carnivorous and others herbivorous, most of them are omnivorous and are content to feed on any thing that comes along their way. Hartley (1947) and Hynes (1950) have discussed the food problems of the fishes and have concluded that many of the fishes can easily be made to change their diet. The same condition was observed here, as a predominantly carnivorous fish like *Mastacembelus pancalus* after starvation, could easily be fed on plant material.

The length of the alimentary canal of all these fishes has also been studied and an attempt has been made to find out a ratio between the standard length of the fish and the gut of animal. As a matter of fact, the length of the alimentary canal in proportion to the body length gives a very important argument in support of their feeding habit. According to Al-Hussaini (1947), the size of the intestine in different fishes varies according to their feeding habits. It is long in the herbivorous fish and small in the carnivorous fish. The same condition has been found in the present study. In predominantly herbivorous fishes like *Labeo* and *Gadusia*, etc., the alimentary canal is very long and lies very much coiled within the body cavity while in the carnivorous fishes like *Belone*, *Notopterus*, *Channa* etc., it is comparatively small.

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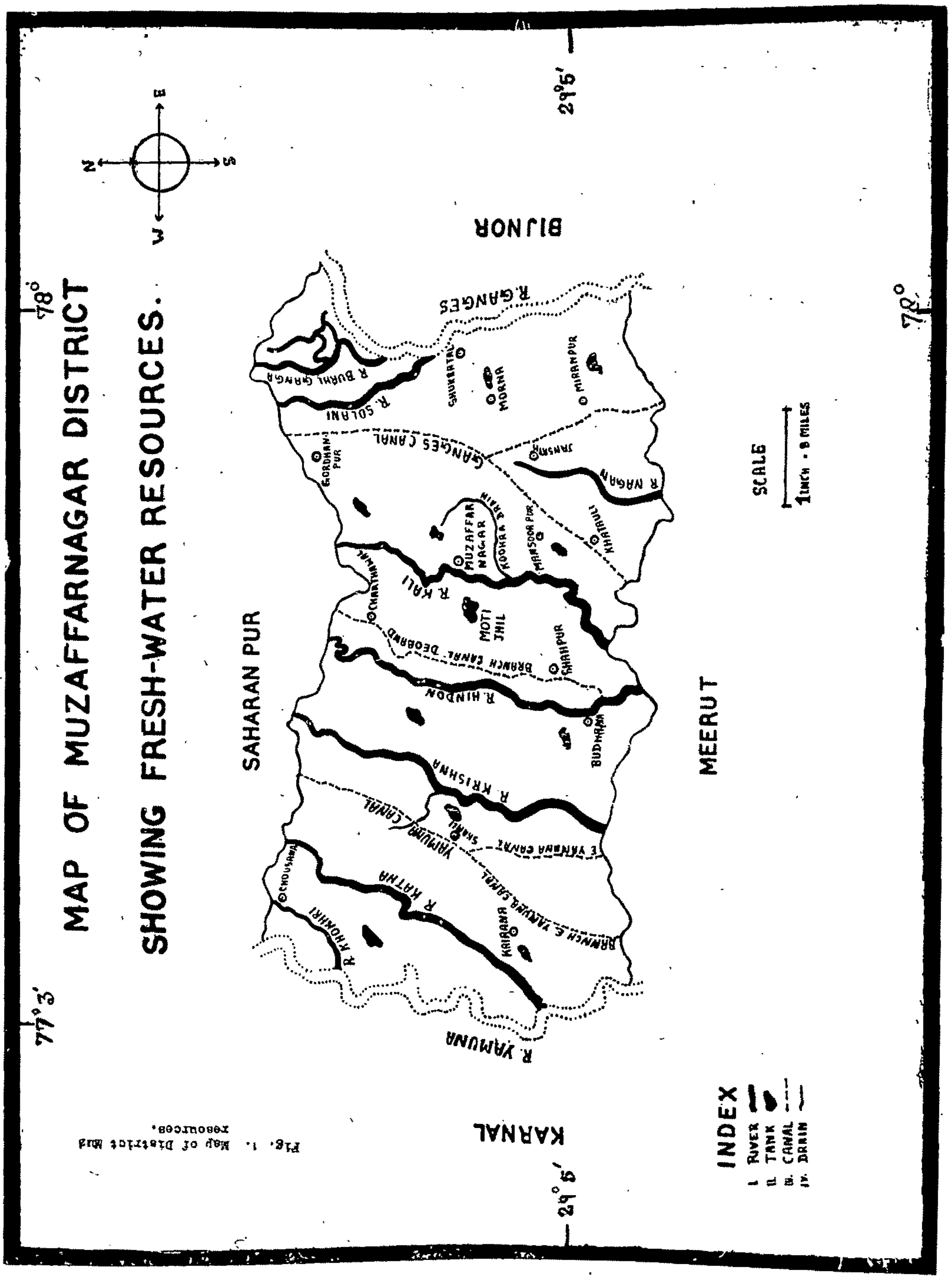

Fig. 1. Map of District Muzaffarnagar resources.

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THE MORPHOLOGY AND BIOLOGY OF *TINGIS BUDDLEIAE* DRAKE (HETEROPTERA : TINGIDAE)*

Part XII. FUNCTIONAL ANATOMY OF THE LEGS AND THE METATHORACIC STINK APPARATUS.

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INTRODUCTION

The recent work of Drake and Davis (1960) on the comparative morphology of Tingidae and certain allied groups of bugs does not give any account of the detailed anatomical peculiarities of this family. This necessitated an intensive work on a type species and *Tingis buddleiae* Drake was chosen, primarily due to its easy availability in Agra. However, works on other groups of Heteroptera occumatate in the literature available and the most recent works of Parsons (1960, 1963) on the thorax of *Gelastocoris* and *Saldula*, both are aquatic bugs, have been taken as basis for this work. Short (1953) is perhaps the first to do a detailed anatomical study of the leg of a typical Heteropteran. The knowledge on the stink glands of Heteroptera has been founded on Brindley's work (1929, 1930 & 1933) and recently Carayon (1962) made a thorough investigation on a couple of species of Tingidae.

The legs (Fig. 1) of *T. buddleiae* are isomorphous with very minor variations. The metathoracic leg has a very small trochantin. Its femur and tibia are longer than those of the pro- and mesothoracic legs. The number of tibial spurs is variable. The metathoracic leg is the longest and is about one and a half times longer than the prothoracic leg. The anatomical descriptions given below refer mainly to the prothoracic leg and the extrinsic muscles of the meso- and metathoracic legs are described separately.

MATERIALS AND METHODS

Tingis buddleiae Drake is a phytosuccivorous bug on *Buddleia asiatica* and *B. madagascarensis* of the family Loghaniaceae. Newly emerged adults were fixed in hot alcoholic bouins fluid and hot Zenker's fluid for 4-6 hours and stored in 70% alcohol. KOH treated materials were used for glycerine and permanent mounts of various sclerites. Musculature has been studied by dissections in canada balsam, stained and dehydrated materials that have been stored in methyl benzoate, as well as by dissecting in water and staining in Mann's methyl blue eosin. For the histological studies of the stink gland, materials fixed in Zenker's fluid were prepared for microtome, following Peterfi's celloidin embedding method. Sections of the thickness of 6-10 μ were cut, stained in Heamatoylin—eosin and mounted in Euparal.

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FUNCTIONAL ANATOMY OF THE PROTHORACIC LEG

(a) *The Coxa*—The sub-globose coxa (Fig. 3), measuring 0·57 mm, is articulated to the pleural articular process (Fig. 5, $PLAP_1$) or "the coxal process" of Parsons (1960), by a distinct dorsomedian knob ($CATK_1$). The proximal posterior and anterior angles rest close to the sternal apophysis (SAP) and the ventral base of the anterior supracoxal flaps, (Fig. 1, ASCF), respectively. The coxal corium or "the pericoxal membrane" unites is to the rim of the coxal cavity (Fig. 3, CC). Thus the coxa is monocondylic. Proximally, a distinct basicostal sulcus (BCS) separates an outer, more chitinised basicoxite or "coxomarginale" (BCX) from an inner basicosta (BCT). The ventral half of the basicoxite is depressed (DBCX) and bears about seven minute bristles (BSP). Corresponding to the number of these bristles there are depressions (DBSP) at the base of the trochantin. These perhaps control the trochantinal movement when the coxal promotors are in action. The distal, setaceous rim of the coxa is produced into a dorsal and a ventral articular knobs (CATK, 2+3). The corresponding cups of the trochanter engage these knobs in the form of a dicondylic, ball and socket joint (Fig. 2, ARF). The coxa is connected to the trochanteral head by connexivum.

(b) *The trochantin* (Fig. 3, TN_1) is a 'V' shaped sclerite with the posterior arm or the basal arm (BA) about one-third the length of the anterior arm. To the basal arm the trochantinal muscles are inserted. The longer anterior arm lies closely applied to the precoxal bridge (Fig. 10, PCB) and its distal free end approximates the pleural articular process. Basally, it articulates with the antero-ventral margin of the coxal cavity, close to the depression on the basicoxite. Akbar (1956) records the trochantin to be attached to the pleural articular process, thereby considering the coxa to be bicondylic in *Leptocorisa.* The trochantin of *T. buddlieae* resembles that of a Mirid (Southwood, 1953) and *Gelastocoris* (Parsons, 1960).

In the metacoxal cavity the pleural articular process (Fig. 10, $PLAP_3$) is placed at the postero-dorsal corner, whereas in the pro- and mesocoxal cavities the processes are placed dorsomedially.

Schiodte (1870) (according to Drake and Davis, 1960), grouped Heteroptera into "Pagiopoda" and "Trochantopoda" depending on the "Cardinate" (limited to back and forth movements) and "rotatory" (free movement of partial rotation around its longitudinal axis) types of metacoxa respectively. Drake and Davis (1960) however, consider the Tingid metacoxa to be fairly advanced in evolution with rotatory type of movements. China and Myers (1929) in Nabids find semi pagiopodous coxae, a condition in between cardinate and rotatory types. The absence of a posterior supra coxal lobe and the reduction of the pleural articular process of the coxal cavity enable the metacoxa in *T. buddleiae* to exercise more freedom of movement than the pro- and mesocoxae.

(c) *Trochanter*—It (Fig. 2) is the most highly sclerotised curved segment of the leg. A sclerotised circular internal ridge (TRR) divides the proximal highly sclerotised portion from the distal rather less sclerotised tubular part. Proximal rim is notched (ARF) dorsally and ventrally for the reception of the coxal knobs. It also bears a dorsal and a ventral apodemal plates (TDP and TVP) that give rise to corresponding elongated trochanteral apodemes. The ventro-lateral margin of the ventral plate gives rise to the apodeme ($TRAP_1$) for the trochanteral levator muscles and the dorsolateral margin of the dorsal plate gives rise to the apodeme ($TRAP_2$) for the trochanteral depressor muscles. The anterior concave surface of the trochanteral head bears a number of short (0·025 mm long) spines (TS_2) ventro-proximally and a couple of very prominent (0·32 mm long) spines (TS_1) dorso-medially. In the prothoracic trochanter these two sets of spines are much spaced out than those of the meso- and metathoracic trochanters.

The distal end of the trochanter articulates with the femur through two condyles ($TRK_{1,2}$). This dicondylic articulation allows back and forth movements only. Trochanter is sparsely clothed with slender setae.

This apparently bisegmented nature of trochanter in *T. buddleiae* is interesting as it is similar to that of Odonata (Snodgrass, 1935). Such a condition is also observed by Southwood (1953) in *Orthotylus* and he homologises the distal "segment" to the basal part of the femur as in Hymenoptera.

(d) *Femur*—Next to the tibia, the sparsely cetaceous femur is the longest of the leg segments (Pro- and meso-thoracic femur 0·64 mm and metathoracic femur 0·82 mm). The anterior and posterior concavities of the femoral head (FS_1 and FS_2) engage the knobs of the trochanter ($TRK_{1,2}$). The femur exhibits tricondylic articulation with the tibia. The medio-anterior part of the distal rim and the lateral portions are notched (FAF) to receive corresponding knobs of the tibial head. The ventral portion of the tibial head and the distal rim of the femur are connected by a wide membrane, elbowing the former along the posterior surface of the latter.

(e) *Tibia*—It is the longest of all the leg segments (pro- and mesothoracic tibia 0·74 mm, and metathoracic tibia 0·9 mm) and closely beset with prominent setae. The dorsal and ventral deeply chitinised margins (DP & VP) of the tibial head give rise to tibial apodemes (TAP_1 and TAP_2) having broad bases. The ventral apodeme has been referred to as the "genuflexor" plate by Akbar (1956) in *Leptocorisa*. The tibial head is much chitinised and slightly bent and is narrower than the distal end. Distally the prothoracic tibia bears

14-16 tibial spurs (TS) while the mesothoracic and the metathoracic tibiae bear 10-12 spurs.

The tibial extrimities of the prothoracic legs are brought in opposition in front and the antenna is drawn out through the spurs for cleaning. This process is repeated several times before and after feeding. The tibial spurs of the meso- and metathoracic legs are used to clean up the abdomen from arrhenaceous bodies. Such behaviour is also reported in *Gelastocoris* by Parsons (1960).

(f) *Tarsus*—The reduction of the tarsus to two segments is the common feature among the Cimicomorph families. Typically in *T. buddleiae* there are two anisomorphous tarsomeres, the proximal segment is here referred to as basistarsus and the distal one as pretarsus.

(g) The triangular *basistarsus* (Fig. 2, BTA) is the smallest of all the leg segments (0·084 mm long) and is produced distally under the base of the pretarsus. Anterior margin of its proximal rim is produced into an articular knob (BTK) that fits into the corresponding notch in the distal rim of tibia. The distal rim has become shifted to the anterior-distal surface, thereby pushing the distal end below the pretarsus as mentioned above. The pretarsal articular knob (PTK) fits into the anterior median notch (BTF) in the proximal rim. Apically, the basitarsus bears a couple of very pronounced basitarsal spurs (BTS).

(h) *The pretarsus*—It (PTA) is (0·17 mm long) about four times as long as the basitarsus and three times as long as thick. Distally, along its dorsal margin there is the 'V' shaped unguifer (UF) which is separated from the pretarsus by a narrow membrane. Medially (Fig. 4) the unguifer is produced into a blunt process (FPU) bearing knobs (FUF) on either side for articulation with the unguis, (UNG) from which it is separated by a membrane. The base of the unguis develops a knob (UNK) that moves in the corresponding depression between the median and lateral processes of the unguifer. Akbar (1955) calls it as "distal tarsal rim of the pretarsus".

The ventral elongated, concave unguitractor plate (UTR), at the base of which is attached the tendon (TUTR) of the pretarsal depressor, is wedged or serrated (WUT) laterally and distally. The unguitractor is connected up to the depression (PAD) of the pseudoarolium of each unguis by a wide membrane, which results in the pulling of the former while the ungues are extended. The lateral serrated margin perhaps acts as an anchor for fixing on the substratum.

At the base of each unguis there is a less sclerotised well differentiated pad that extends up to the middle of the former. This pad represents the "pseudoarolia" (PAR) of Mirids and *Thaumastocoris* of Southwood (1953). Drake and Davis (1960) call this as the "peculiar tooth" in the case of Tingidae and Deraeocorinae and suggest the absence of arolia and pseudoarolia in Tingidae. There is however no true arolium in *T. buddleiae*.

Musculature of prothoracic leg

The musculature of the legs is fundamentally similar except for minor variations in the places of attachment of the extrinsic muscles. The musculature is more or less similar to that of other Heteroptera described by earlier workers. All the proscutal muscles originate from the crescentic proscutal apodeme. The musculature of the legs is treated under the following categories depending on the places of insertion (1) the trochantinal muscles (2) the basicoxite muscles (3) the trochanteral muscles (4) the femoral muscles (5) the tibial muscles and (6) the tarsal muscles.

1. *The trochantinal muscles* are represented by the following two sets:—

(a) *The primary trochantinal promotor of the coxa* (38) consists of long, stout fibres that run obliquely to get attached to the proscutal apodeme very close to the occipito-cervical muscle of the proscutum (PSC). This muscle represents the "tergal promotor" of *Naucoris* (Rawat, 1939) "first promotor of coxa" of *Leptocorisa* (Akbar, 1956) and the "muscularis noto trochantinalis" of *Gelastocoris* (Parsons, 1960).

(b) *The secondary trochantinal promotor of coxa* (39) consists of rather short, stout fibres that run vertically to get attached to the proepimeron (EM_1). The muscle may correspond to the "sternal promotor of coxa" of *Nezara* (Malouf, 1932) and the "third promotor of coxa" of *Leptocorisa* (Akbar 1956).

These two trochantinals aid in rotating the leg. Parsons (1960, 63) however, records only one set of trochantinal muscles that arise from the proscutum.

2. *The basicoxite muscles comprise the following three sets:—*

(a) *The tergal promotor of coxa* (36) is a fan shaped muscle, the powerful fibres of which arise from the proscutal apodeme, close to the primary trochantinal promotor and get inserted through tendon on the basicoxite, close to the trochantinal base. This muscle represents the "tergal promotor of coxa" of *Nezara* (Malouf, 1932), "internal rotator" of *Naucoris* (Rawat, 1939), "second promotor of coxa" of *Leptocorisa* (Akbar, 1956) and "muscularis notocoxalis primus" of *Gelastocoris* (Parsons, 1960). This muscle rotates the coxa.

(b) *The tergal remotor of coxa* (37) is a set of large number of long, stout fibres originating on the proscutal apodeme, close to the depressor of the prealar bridge and getting insertion through tendons on the basicoxa, at the postero-dorsal base of the coxa. This muscle corresponds to the "tergal remotor of coxa" of *Nezara* (Malouf), and *Naucoris* (Rawat); "first remotor of coxa" of *Leptocorisa* (Akbar) and "muscularis notocoxalis tertius" of *Gelastocoris* (Parsons).

(c) *The pleural remotor of coxa* (40) is a fairly large bundle of fibres arising on the proepimeron and getting insertion close to the tergal remotor of coxa. This corresponds to the "sternal remotor of coxa" of *Nezara* (Malouf), and the "muscularis pleuracoxalis" of *Gelastocoris* (Parsons).

The tergal and pleural remotors rotate and adduct the leg.

3. *The trochanteral muscles* consist of the following four sets:—

(a) *The tergal depressor of trochanter* (41) consists of long, strong fibres originating on the proscutal apodeme, close to the tergal remotor of coxa and get inserted through tendons on the ventral apodeme (TRAP$_2$) of the trochanteral head. This muscle corresponds to the similar muscle of Malouf and Akbar; "extra coxal depressor branch from tergum" of Rawat; part of "nototrochanteralis" of Larsen (1945) and Parsons (1960).

(b) *The pleural depressor of trochanter* (42) arises from the pleural bridge, in between the pleural promotor and remotor of the coxa and gets inserted through tendons at the same apodeme where the tergal depressor of trochanter is inserted. It corresponds to the "pleural branch of the depressor of trochanter" of *Nezara* (Malouf) and the "muscularis pleura-trochanteralis" of *Gelastocoris* (Parsons).

The tergal and pleural depressors depress the trochanter.

(c) *The coxal depressor of trochanter* (43) consists of a few short, stout, fibres originating on the posterior corner of the coxa and get inserted through tendon on the ventral apodeme (TRAP$_2$) of the trochanter, close to the insertion of the above mentioned two muscles. This muscles corresponds to the "muscularis coxatrochantiralis medialis" of *Gelastocoris* (Parsons). This depresses the trochanter.

(d) *The levator of trochanter* (44) is a very large muscle consisting of many, short, stout fibres occupying the entire coxa, spreading uniformly on its dorso-mesal expansion and extending up to the pleural articular processes (PLAP$_1$). All the fibres are inserted through tendons on the broad antero-dorsal apodemal plate (TRAP$_1$) of the trochanteral head. It corresponds to the "muscularis coxa trochantiralis lateralis" of *Gelastocoris* (Parsons). Contraction of these fibres lifts the trochanter.

4. *The femoral muscle* consists of only the femoral remotor or the redductor of the femur (Fig. 2), whose short parallel fibres originate (45) on the dorsal wall of the distal arm of the trochanter and get inserted on the ventral margin of the femoral head similar to that of *Orthotylus* (Southwood, 1953). It corresponds to the "remotor of femur" of Malouf (1932).

5. *The tibial muscles* comprise three sets that originate along the entire length of the femur and get inserted on the apodemes of the dorsal plate and the ventral or "genuflexor" plate of the tibial head. The apodeme (TAP$_1$) of the dorsal plate is inverted 'L' shaped. At its angle and at the free end of the short arm (TDA) are inserted the tendons of the first levator and second levator of the tibia respectively. This condition of the apodeme of the dorsal plate increases mechanical advantage. The apodeme (TRA$_2$) of the ventral plate is rather broad and has a longitudinal slit along the middle.

(a) *The primary levator of tibia* (46) originates along three-fourth the length of the dorsal inner surface of the femur and gets inserted at the angle of the apodeme of the dorsal plate. It corresponds to the "extensor of tibia" of Akbar (1956) and the "muscularis levator tibiae" of Parsons (1963).

(b) *The secondary levator of tibia* (47) is a single bundle of strong fibres originating on the transverse ridge of the trochanter (TRR) and through long tendon gets inserted at the free end of the short arm of the dorsal apodeme. A couple of fibres originate on the dorsal wall of the distal arm of the trochanter.

The contraction of these two sets of muscles levates the tibia.

(c) *The depressor of the tibia* (48) is a large muscle whose fibres originate along the ventral inner surface of the femur and get inserted through tendons on the apodeme (TAP_1) of the ventral plate of the tibial head.

6. *The tarsal muscles* are the depressors of basitarsus and pretarsus.

(a) *The depressor of the basitarsus* (49) is a very small set of two fine fibres originating on the mid-ventral wall of the tibia and get inserted through a delicate tendon to the basiventral angle of the basitarsus.

Contraction of these fibres depresses the basitarsus and indirectly depresses the pretarsus.

(b) *The primary depressor of the pretarsus* (50) has fairly widely spread out fibres, originating on the mid-dorsal wall of the femur. These fibres are connected by a common tendon which is inserted at the basal angle of the triangular unguitractor plate. This muscle corresponds to the "proximal muscle of the depressor of pretarsus" of Akbar (1956) and the "muscularis depressor praetarsi primus" of Parsons (1960). Short (1953) however, overlooked this important muscle in *Corixa*.

(c) *The secondary depressor of pretarsus* (51) consists of three or four short feeble fibres originating on the proximal dorsal wall of the tibia and get inserted on the tendon of the primary depressor of pretarsus. It corresponds to the "flexor of pretarsus" of Short (1953).

These fibres aid in manipulating the movements of claws, the unguifer acting as pivot.

EXTRINSIC MUSCLES OF THE MESOTHORACIC LEG

The extrinsic muscles of the mesothoracic leg that originate on the mesotergum and the mesopectus include—(a) The trochantinal muscles, (b) The bosicoxite muscles and (c) The trochanteral muscles.

(a) *The trochantinal muscles* (Fig. 8)

(i) *The primary Trochantinal promotor of mesocoxa* (62) that originates on the free end of the mesosternal apophysis (SAP_2) is inserted on the basal arm of the mesocoxal trochantin (TN_2).

(ii) The secondary trochantinal promotor of mesocoxa (63) originates on the mesoscutum and gets inserted at the basal arm of the mesocoxal trochantin.

(b) *The meso-basicoxite muscles*

(i) *The tergal promotor of coxa* (64) is a large bundle of stout fibres, originating on the median area of the mesoscutum, close to the origin of the oblique longitudinal muscle and getting inserted at the basal angle of the coxa, close to the trochantinal base.

(ii) *The tergal remotor of coxa* (65) consists of long, stout fibres, originating on the lateral area of the mesoscutum and getting insertion at the outer angle of the coxa.

(iii) *The pleural remotor of coxa* (66) is a fan shaped muscle, whose fibres originate on the meso-episternum at the basal angle of the pleural apophysis (PAP) and get inserted along with the tergal remotor of the coxa on the outer angle of the latter.

(c) *The trochanteral muscles*

(i) *The tergal depressor of trochanter* (67), that originates on the lateral area of the mesoscutum and gets inserted on the ventral plate of the trochanteral head.

(ii) *The pleural depressor of trochanter* (68) is a bundle of large strong fibres, originating along the inner angle of mesopleural apophysis (PAP). These fibres are connected by tendons, to the ventral plate of the trochanteral head.

THE METACOXAL EXTRINSIC MUSCLES (FIG. 8)

(a) *The tergal promotor of coxa* (73) that forms the major set, whose long, stout fibres originate on the metascutum and get inserted on the ventral angle of the metacoxal rim.

(b) *The tergal remotor of coxa* (74) consists of fairly long, strong fibres, running from the metascutum to the dorsal angle of the metacoxa.

(c) *The pleural remotor of coxa* (75) is a fan shaped muscle, whose strong fibres originate on the metaepisternum (MTEPS) and get inserted on the postero-dorsal angle of the metacoxa.

(d) *The tergal depressor of trochanter* (76) originates on the meta-scutum, close to the other metascutal muscles and get inserted, through tendons, on the ventral plate of the trochanteral head.

(e) *The pleural depressor of trochanter* (77) is a fan shaped muscle, the strong, long fibres of which originate along the dorsal area of the episternum and get inserted on the ventral apodeme of the trochanter.

The meta-trochantinal muscles are not traced in *T. buddleiae*.

THE ANATOMY OF THE METATHORACIC STINK OR SCENT APPARATUS

The metathoracic stink apparatus (Fig. 11) in *T. buddleiae* consists of the specially modified metasternum (Fig. 10), a spherical median gland (SG) and an elongated lateral reservoir (SGRE), symmetrically located on either side. In dissected materials, the gland appears as a rosette with a stalk (duct) (DSG) and the reservoir appears wrinkeled, having longitudinal striations. In KOH treated materials, the stalk as well as the reservoir remain chitinous.

The orifice (Fig. 12, SGO) of this odoriferous gland is situated in the post-coxal bridge (PTCB), immediately posterior to the pleural articular process ($PLAP_3$). The epimeral area (EM_3) in front of the orifice is spatulate externally, forming the scent gland ostiole (SGOS) or "ostiole odorifique" of Carayon (1962). The site of the odoriferous orifice is variable in different groups of Heteroptera; "at the end of the coxal cleft in the lower anterior corner of the episternum" (Taylor, 1918) and "at the base of the furca or meta sternal apophysis" (Brindley, 1930 and '38; Drake and Davis, 1960; Parsons, 1960; and Carayon 1962).

The ostiole then continues ventro-anteriorly as semicircular scent groove (Fig. 12, SGR), bordering the ventral half of the coxal cavity and, as in other Heteroptera (Brindley, 1938 and Parsons, 1960), anteriorly divides the precoxal bridge into an anterior laterale (Fig. 10, ALA) and a posterior antecoxal laterale (PLA). The scent groove is marked internally by a wide scent ridge (SR). The metasternal apophysis (SAP_3) appears to develop from the middle of this ridge. Anterior to this apophysis, the scent ridge develops a marginal semimembranous narrow flap, to which the connexival membrane of the coxa is attached. The flap is called the "pericoxal flange" (PCF). The "stink fold" of Akbar (1958) and the "narrow and larger flaps" of Parsons (1960) are not marked in *T. buddleiae.*

The histology of the gland (Fig. 13) shows two distinct regions, each differing in staining reaction. The outer, cortical region (COR) is formed of a single layer of cuboidal epithelial cells, with large, round, granular, eosinophilic, granular cytoplasm. The inner, medullary region (MED) stains deep blue (chitin) in Mann's methyl blue-eosin and is transversed by many minute canaliculi (CAN) or "intracellular ductule" of Brindley (1929, '30). The canaliculi surrounded by nonsecretory indistinct cells, unite to form the common collecting or efferent duct (CD), that forms the stalk or duct (DSG) of the gland.

The elongated, saccular reservoir extends from the fourth to the sixth abdominal segments. It (Fig. 14) has a single layer of nonsecretory, undifferentiated epithelial cells, placed on distinct basement membrane (BM). The lumen is lined by corrugated layer of intima (INT). The reservoir has a distinct conducting duct (RD) or "conduit du reservoir" of Carayon (1960), which joins the efferent or collecting duct at its opening into the common space, the atrium (Fig. 12, ATR). The atrium empities into the scent gland ostiole (SGOS) through the orifice (SGO), that is situated at the post coxal bridge. The atrial roof (post-coxal bridge, $PTCB_3$) is produced into a finger shaped apodeme (AP_{69}) for the insertion of the dilator muscle of the scent gland orifice. The muscle fibres originate on the third phragma (Fig. 9, PH_3). Contraction of this muscle lifts the apodeme and opens the orifice, allowing the secretion to flow into the spatulate ostiole where it evaporates. Thus the ostiole serves as the "evaporating surface" and there is no special device as the "shiny band" of *Gelastocorisa* (Parsons, 1960) serving similar purpose. The gland is innervated by a branch from the nervous abdominalis primus (Fig. 9, N. AB_1).

Drake and Davis (1960) consider the reservoir as the "grandular diverticulum", representing the lateral sac of the median invagination, the median portion of which (here described as gland) having been obliterated. These authors refer to this condition as secondary specialization similar to most of the Cimicomorpha. Brindley (1929, '30 and '33) describes paired tubular glands with a common reservoir, the latter again been provided with an asymmetrical accessory gland in most of the Heteroptera studied by him. The microstructure of the metathoracic odoriferous glands of many species of Tingidae and allied families was studied recently by Carayon (1962). He however describes a tubular glandular part in the stink apparatus of *Cantacader of zeli*. Studies in *T. buddleia* confirm his histological findings.

SUMMARY

The legs of *Tingis buddleiae* Drake, though isomorphous, show minor variations with regard to the coxal extrinsic muscles. The absence of the posterior supra-coxal lobe and the reduction of trochantin in the metacoxa enable the metathoracic leg to have more freedom of movement, a type of rotatory condition. There are two tarsal segments. The pretarsus is about four times as long as the basitarsus and is provided with elaborate anchoring devices. The metathoracic scent apparatus is operated by a set of muscles and innervated by a branch from the first abdominal nerve. The reservoir is much elongated, longer in proportion to the gland.

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FIGURE LETTERING

ABST$_1$	First abdominal sternite.
ALA	Anterior laterale
AP$_{69}$	Apodeme of the dilator muscle of the stink orifice.
ARF	Articular facet of the trochantiral head.
ASCF$_1$	Prothoracic anterior supra coxal flap.
ATR	Atrium.
BA	Basal arm of the trochantin.
BCS	Basicostal sulcus.

BCT	Basicosta.
BCX	Basicoxite.
BM	Basement membrane.
BSD	Basisternal depression to receive the pro-coxa.
BSP	Basicoxite bristles.
BTA	Basitarsus.
BTF	Median basitarsal facet.
BTK	Articular knob of basitarsus.
BTS	Basitarsal spurs.
CAN	Canaliculi of the scent gland.
$CATK_1$, $CATK_2$ and $CATK_3$—	Proximal median, distal dorsal and distal ventral articular knobs of the coxa.
CC	Coxal cavity.
CD	Collecting duct.
COR	Cortex.
CX_1 to CX_3—	Pro-, meso- and metacoxae.
$CXCL_2$	Meso coxal cleft
DBCX	Basicoxite depression.
DBSP	Trochantinal depressions for basicoxite bristles.
DP	Dorsal chitinised margin of the tibial head.
DLSG	Dorso-lateral abdominal scent gland.
DSG	Duct of the scent gland.
EM_1	Pro-epimeron.
EM_3	Metaepimeron
ES_1	Pro-episternum.
ES_3	Meta episternum.
EVP	Scent gland evaporatorium.
FAF	Femoral articular facet.
FE	Femur.
FS_1 and FS_2—	Sockets of the femoral head.
FPU	Blunt median process of the unguifer.
FUF	Lateral knobs of the unguifer.
INT	Intima
LSGRE	Lumen of the scent gland reservoir.
MED	Medulla.
MTEPS	Metathoracic episternum.
MTS	Metathoracic spiracle.
$N.AB_1$	Nervus abdominalis primus.
PAD	Depressions of the pseudo-arolium.
PAR	Pseudo-arolium.
PAP	Mesopleural apophysis, PCB_3—meta-precoxal bridge.
PCF	Meta-pericoxal flange.
$PLAP_1$ and $PLAP_3$—	Pro and meta articular processes.
PLA	Posterior laterale
PLB	Propleural bridge
PLR_3	Metapleural ridge.
PLS_1	Propleural sulcus.
PPNE	Posterior pronotal extension
PSC	Proscutum.
$PSCF_1$	Posterior supra-coxal flap of the prothorax.
PTA	Pretarsus
PTK	Articular knob of the pretarsus.
PTCB	Meta-post coxal bridge.
RD	Reservoir duct.

SAP$_2$	Mesosternal apophysis.
SAP$_3$	Metasternal apophysis
SCF$_3$	Metathoracic supra coxal flange.
SCS$_3$	Meta-sternacostal ridge.
SF$_1$ to SF$_3$	Pro-meso- and metathoracic sternal furrow.
SG	Metathoracic scent gland
SGO	Scent gland orifice.
SGOS	Scent gland ostiole.
SGR	Scent groove.
SGRE	Scent gland reservoir.
SR	Stink ridge.
TAP$_1$ and TAP$_2$	Dorsal and ventral apodemes of the tibial head.
TB	Tibia
TBC	Tibial condyle.
TD$_{36}$ to TD$_{40}$	Tendons of muscles numbers 36–40
TDA	Short arm of the tibial dorsal apodeme.
TDP	Dorsal plate of the trochanteral head.
TN$_2$	Meso trochantin
TR	Trochanter.
TRAP$_1$	Trochanteral dorsal plate apodeme.
TRAP$_2$	Trochanteral ventral plate apodeme.
TRK$_1$ and TRK$_2$	Trochanteral articular knobs for the femoral head.
TRR	Trochanteral ridge.
TS	Tibial spurs
TS$_1$ and TS$_2$	Trochanteral spurs.
TUTR	Tendon of the unguitractor plate
TVP	Ventral plate of the trochanteral head.
UF	Unguifer
UNG	Unguis
UNK	Knob of the unguis
UTR	Unguitractor plate.
WUT	Wedges of the unguitractor plate.

MUSCLES

36. Tergal promotor of coxa
37. Tergal remotor of coxa
38. Primary trochantinal promotor of coxa
39. Secondary trochantinal promotor of coxa
40. Pleural remotor of coxa
41. Pleural depressor of coxa
42. Pleural depressor of trochanter
43. Coxal depressor of trochanter
44. Levator of trochanter
45. Redductor of femur.
46. Primary levator of tibia
47. Secondary levator of tibia.
48. Depressor of the tibia.
49. Depressor of basitarsus.
50. Primary depressor of pretarsus.
51. Secondary depressor of pretarsus.
62. Primary trochantinal promotor of meso-coxa.
63. Secondary trochantinal promotor of mesocoxa
64. Tergal promotor of mesocoxa.
65. Tergal remotor of mesocoxa.

66. Pleural remotor of mesocoxa.
67. Tergal depressor of trochanter
68. Pleural depressor of trochanter
69. Dilator of the metathoracic stink gland orifice.
73. Tergal promotor of metacoxa.
74. Tergal remotor of metacoxa.
75. Pleural remotor of metacoxa.
76. Tergal remotor of metacoxa.
77. Pleural depressor of meta-trochanter.

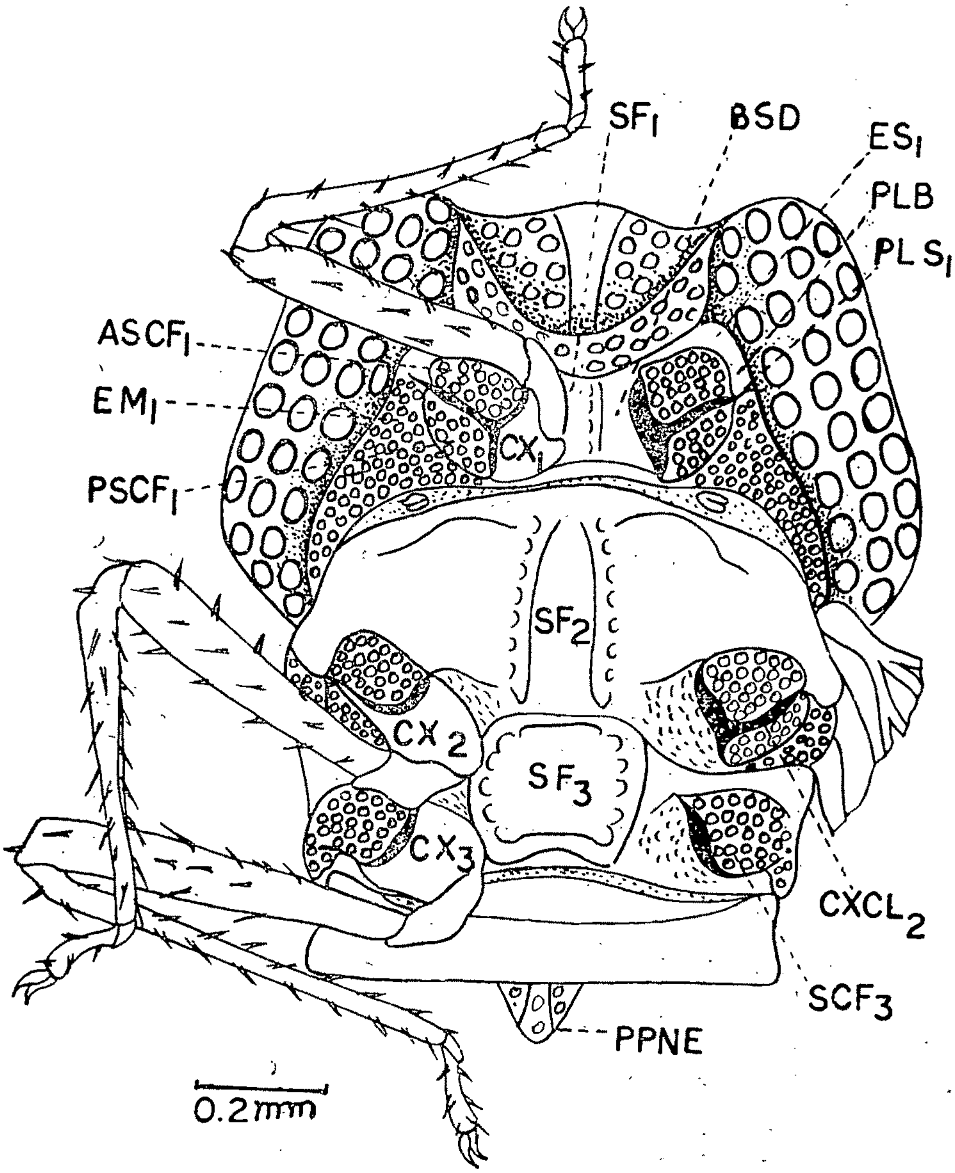


Fig. 1. Ventral view of the thorax.

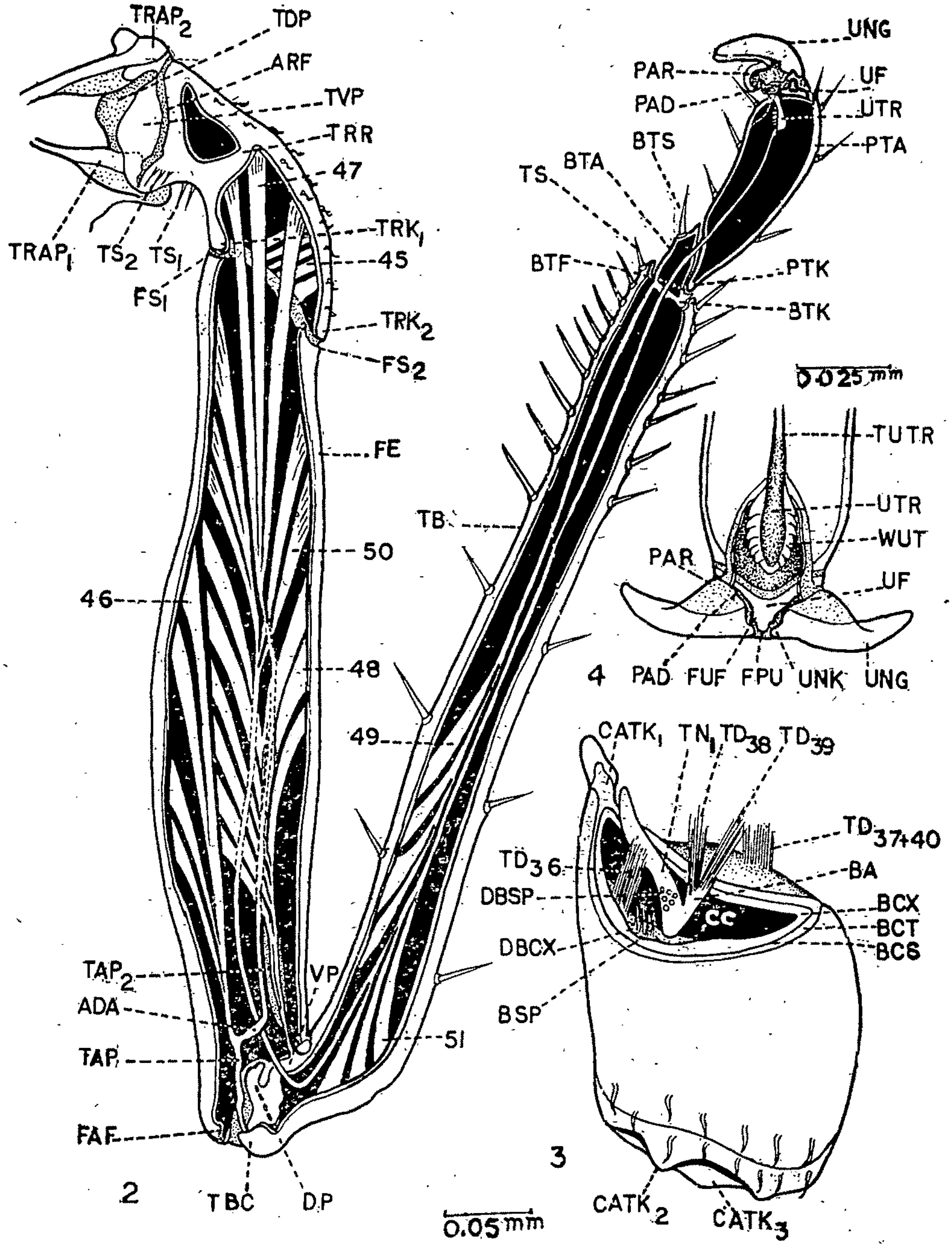
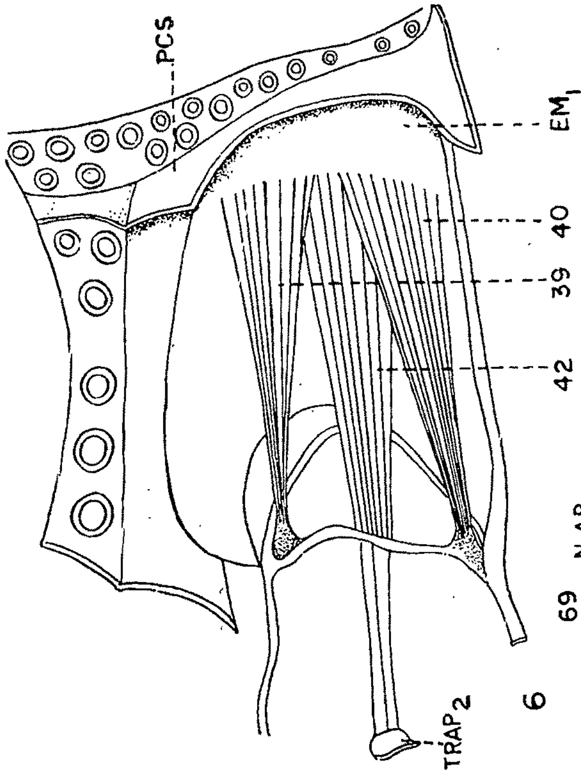
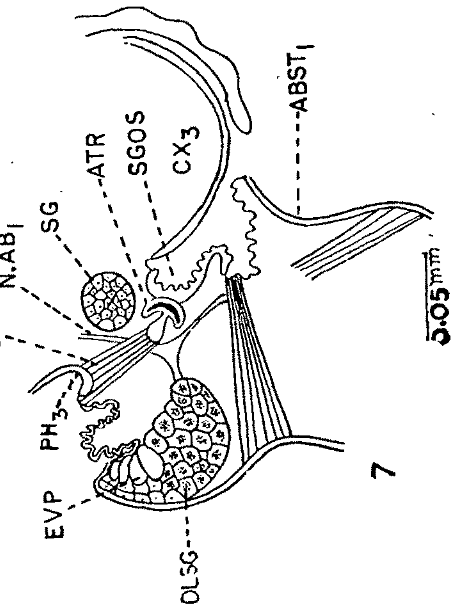


Fig. 2. Prothoracic leg and its musculature (Coxa removed)
Fig. 3. Lateral view of the pro-coxa.
Fig. 4. Distal end of the pretarsus.





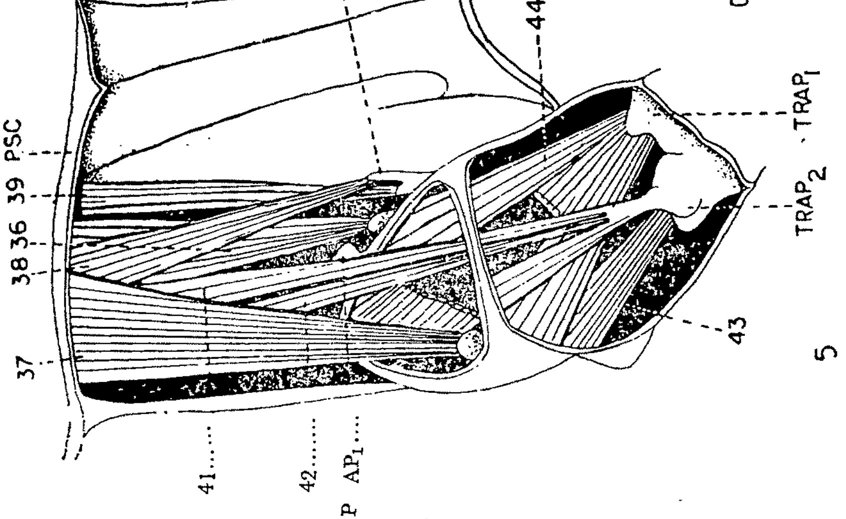
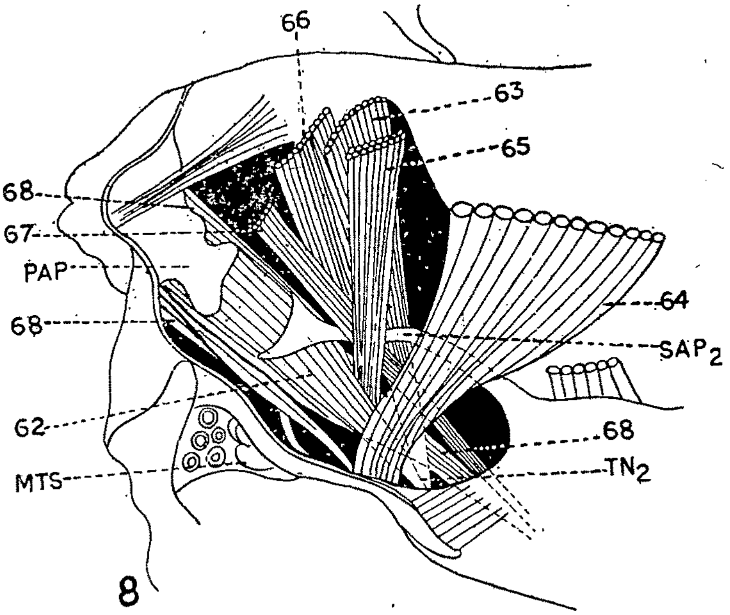


Fig. 5. Protergal musculature (leg muscles only)

Fig. 6. Propleural musculature (leg muscles only)

Fig. 7. Sagittal section at the lateral margin of the theracico-abdominal junction showing the stink apparatus.



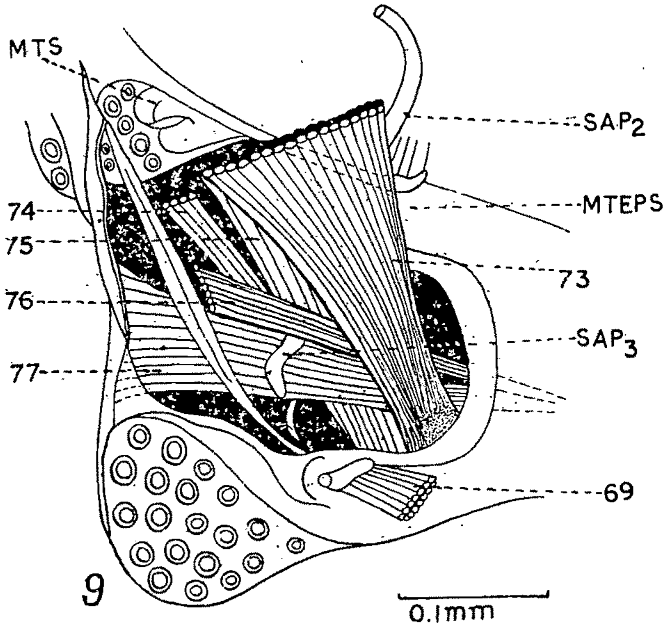
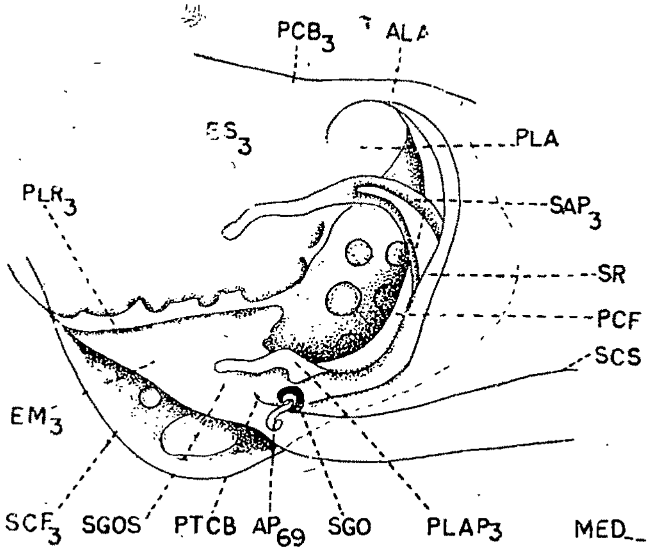


Fig. 8. Mesocoxal musculature.
Fig. 9. Metacoxal musculature.



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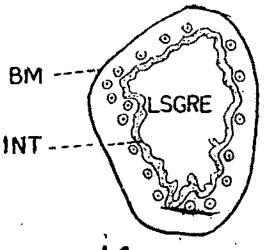

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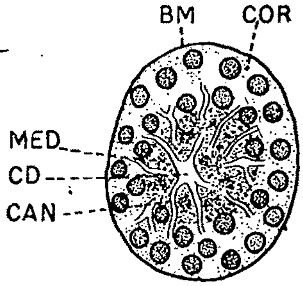

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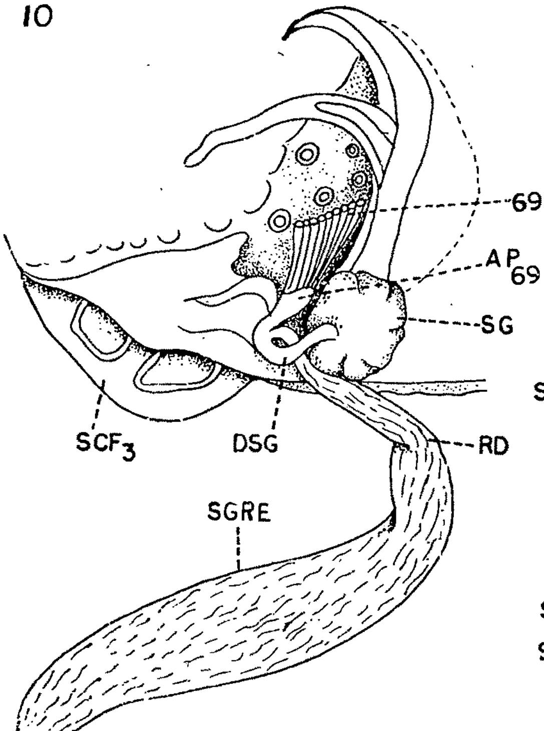

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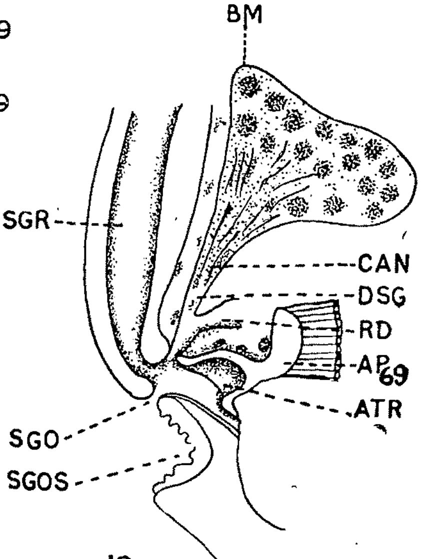

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Fig. 10. Inner view of the metacoxal region of the metasternum.
Fig. 11. Metathoracic scent apparatus.
Fig. 12. Oblique section of the metathoracic scent apparatus.
Fig. 13. T.S. of the metathoracic scent gland
Fig. 14. T. S. of the reservoir of the scent gland.

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STUDIES ON VOLATILE FATTY ACID PRODUCTION, NITROGEN UTILIZATION AND MICROBIAL POPULATION IN THE RUMEN OF BUFFALO AND ZEBU

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The investigation under report was designed to make a comparative study of the nitrogen containing substances as well as certain aspects of cellulolytic activity and associated variations in microbial population in the rumen of buffalo and zebu.

MATERIAL AND METHOD

1. *Animal*

Two buffalo and two zebu bullocks were used for the investigation and each of them was fed concentrate mixture at maintenance level alongwith 5 lb. of Berseem (Trifolium alexandrinum). The concentrate and the green was offered in two equally divided portions at 8 a. m. and 3 p. m., and was followed by *ad lib* wheat straw whose daily intake was recorded. The animals were watered after collection of the rumen liquor at 10 a.m. and 3 p.m.

The ingredients of the concentrate mixture and their relative proportions were :

Wheat bran	30 lb.
Crushed barley	25 lb.
Crushed gram	25 lb.
Groundnut cake	20 lb.
Mineral mixture	2 lb.

This mixture contained 15·3 lb. DCP and 69·5 lb. SE/100 lb.

2. *Sampling and processing of rumen liquor*

Samples of rumen liquor (RL) were obtained as described by Pant *et al.*, (1962) at 8, 10, 13, 15, 17, 20 and 22 hours and immediately strained through double folded fine muslin cloth. Further processing of strained rumen liquor (SRL) was carried out as stated below :

(a) SRL was centrifuged at 1000 r.p.m. for one minute to allow the settling of suspended food particles and protozoa. The supernatant obtained is CRL_1.

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(b) The supernatant obtained by centrifugation of CRL_1 at 5000 r.p.m. for fifteen minutes is CRL_5.

3. *In vitro estimation of cellulolytic activity*

To estimate the relative cellulolytic activity of SRL two pairs of glass artificial rumen (GAR) as designed by Barnett and Reid (1957) were used simultaneously for each experiment. Each GAR was charged with 50 ml. mineral solution (Burroughs *et al.* 1950) and 225 ml. of distilled water and allowed to reach a temperature of 39°C by standing in a thermostatic water-bath overnight. In one GAR of each pair 2·5 g cellulose powder was added as substrate while the other, without cellulose, served as control. The contents were inoculated with 50 ml. SRL; Co_2 was bubbled for ten minutes before inoculation and at 4 hourly intervals for the next 48 hours to maintain anaerobiosis.

Samples were withdrawn at every 8 to 10 hourly interval for pH estimation and at 0, 24 and 48 hours for TVFA estimation. The tendency for pH to fall below 6·5 to 6·7 was checked by adding sodium carbonate solution 106g/Litre).

4. *Analytical methods*

(a) TVFA and NH_3 were estimated in CRL_5 by the methods reported earlier by Pant *et al.* (1962).

(b) For the estimation of total-N and different fractions of nitrogen containing substances, SRL, CRL_1 and CRL_5 were digested according to the nesslerization procedure of Koch and Mc Meekan (1924). The values obtained by subtraction of CRL_1—N from SRL—N and CRL_5—N from CRL_1—N and NH_3—N from CRL_5—N have been referred as Food and protozoal-N, Bacterial—N and Peptide and amino-N respectively.

(c) Total bacterial and protozoal counts in SRL were carried out according to Gall *et al.* (1949) and Moir (1951) respectively.

(d) pH estimation. The pH of SRL and GAR content was measured with Beckman pH Meter (Model H—2).

(e) Redox potential was measured by the method of Broberg (1957).

5. *Statistical analysis*

The statistical analyses of the data were carried out by methods described by Snedecor (1946).

RESULTS AND DISCUSSION

1. *Volatile fatty acid production and cellulolytic activity in the rumen of buffalo and zebu*

In Fig. 1 data have been graphically represented on the concentration of TVFA in the rumen liquor of buffalo and zebu at different intervals after feeding. At 8 hours (i. e., immediately before morning feeding) the TVFA level is

59·57 and 61·58 m. eq/litre CRL$_5$ and at 10 hours 72·44 and 74·45 m. eq./litre CRL$_5$ in zebu and buffalo respectively. The difference in the concentration of TVFA at these intervals is highly significant ($P \angle 0{\cdot}01$) in both the species. Comparison of the variation in TVFA concentration of CRL$_5$ at 8 hours, 13 hours and 15 hours are of no statistical significance in both the species. The rise in TVFA concentration at 10 hours is obviously entirely due to the degradation of the ingested ingredients of the concentrate mixture and green fodder. At 13 hours the decline in TVFA level from that obtained at 10 hours is higly significant ($P \angle 0{\cdot}01$) in buffalo and significant in zebu ($P \angle 0{\cdot}05$). The concentration at this hour is 64·01 and 61·36 m. eq/litre CRL$_5$. The data permit the conclusion that the decline in TVFA concentration observed at 13 hour is due to dilution by water intake at 10 hours and partly due to the absorption of TVFA from reticulo-rumen as well as its onward passage. The pH and redox potential values (Table 1) decreased in zebu from 6·87 and —369·2 mV at 10 hours to 6·75 and —375 mV at 13 hours. In buffalo the pH value declined from 6·81 at 10 hours to 6·77 at 13 hours and the redox-potential value remained almost similar being —378·9 and —379·5 mV at 10 and 13 hours respectively. The declining pH and increased or similar reducing capacity of rumen contents rules out the possibility of decreased TVFA production and/or microbial activity at 13 hours.

While the TVFA concentration at 15 hours was not significantly higher from the concentration recorded at 13 hours, the concentration at 17 hours was higher ($P \angle 0{\cdot}01$) in both the species, the values being 90·06 and 91·62 m.eq/litre CRL$_5$ in zebu and buffalo respectively. This steep rise in the TVFA was in all probability due to its production from the fermentation of concentrate mixture and greens fed at 15 hours besides that from the digestion of straw ingested at 8·30 hours and onwards. The second probability is based on the observation reported by Hale *et al.* (1947) that cellulose digestion reaches its maximum at 6 hours after ingestion and is maintained for a further period of 6 hours. The rate of cellulose breakdown would not only be high at this hour but is likely to be further accentuated by reactivisation of rumen microbes because of the availability of soluble carbohydrates and nitrogen from the ingestion of concentrate mixture and greens at 15 hours.

A comparison of the TVFA concentrations, between the two species, did not reveal any significant difference at any given hour and to that extent failed to indicate significant variation in the cellulolytic activity of rumen microbes. The variations in pH as well as redox potential values observed at different intervals after feeding are in agreement with this conclusion.

In Table 2 have been collected the data on the digestion of cellulose *in vitro*. In both the species cellulose digestion began at a faster rate after 24 hours of incubation and there was highly significant difference ($P \angle 0{\cdot}01$) in the concentration of TVFA in GAR contents between 24 and 48 hours of incubation. The difference in the TVFA concentration in GAR contents between species was not statistically significant indicating again the absence of any variation in the cellulolytic activity of rumen microbes of the two species.

Although the TVFA concentration in the rumen contents observed *in vitro* and *in vivo* did not reveal any significant variation in the cellulolytic activity of the two species, the fact that a higher proteolytic and protein synthesizing activity was observed in buffalo (vide infra) together with the facts that no data on the rates of absorption or utilization by microbes or dilution by saliva and water of TVFA could be collected, make it extremely difficult to conclude that in the two species the cellulolytic activities are not different; neither to indicate which of the interacting factors were responsible for identical values of TVFA assuming that the cellulolytic activities were different. It certainly appears that estimation of TVFA concentration alone can not be considered as a valid criterion to assess cellulolytic activity perhaps the per cent digestibility of cellulose is likely to be a more suitable index for comparing the cellulolytic activities of rumen inoculum.

2. *Nitrogen utilization in the rumen*

The data on the total nitrogen and its various fractions viz., food and protozoal nitrogen, bacterial nitrogen, amino and peptide nitrogen and ammonia nitrogen in the rumen contents of zebu and buffalo at different intervals after feeding have been graphically represented in Fig. 1 and their overall averages and analysis of variance collected in Tables 3 and 4 respectively.

The concentration of total nitrogen in SRL of both the species fluctuated at different intervals after feeding; there was a significant increase ($P \angle 0{\cdot}01$) in its concentration two hours after the morning feed (10 hours) followed by a significant decline at 13 hours ($P \angle 0{\cdot}01$). This increase, like TVFA at 10 hours, was due to the ingestion of nitrogenous constituents of the concentrate mixture and green and the decline at 13 hours was partly due to the absorption of ammonia and the onward passage of the soluble derivatives of degraded protein. There was a significant difference ($P \angle 0{\cdot}05$) in the overall concentration of total nitrogen between the species, the values for zebu and buffalo being 59·95 and 62·97 mg.% respectively.

The overall concentration of food and protozoal nitrogen was significantly higher in zebu than in buffalo ($P \angle 0{\cdot}01$), the respective values being 21·15 and 17·73 mg. per cent. Since the food and protozoal nitrogen was not partitioned, it is not possible to say which component was responsible for the higher value Furthermore, the observations that the bacterial and ammonia nitrogen were significantly higher in buffalo and no significant difference existed in the concentration of amino and peptide nitrogen in the two species, together with the fact that the total number of protozoa was more in buffalo than in zebu (vide infra) tend to emphasize that the significantly higher concentration of food and protozoal nitrogen in zebu is in all probability due to the greater quantity of undigested nitrogen fraction of food.

The concentration of bacterial nitrogen was higher in buffalo than in zebu at all intervals and the difference between the overall concentration in the two species was highly significant ($P \angle 0{\cdot}01$), the concentrations being 16·31 and 12·81 mg.% in CRL$_1$ of buffalo and zebu respectively. The differences in the concentration of bacterial nitrogen between intervals were significant ($P \leqslant 0{\cdot}01$), indicating that the diurnal variations are not as great as the variation between species.

There was highly significant variation ($P \angle 0{\cdot}01$) in the concentration of alfa-amino and peptide nitrogen in both the species between different intervals but not between the species.

The peak in the concentration of NH_3 nitrogen in both the species was observed at 10 and 17 hours i.e., two hours after the ingestion of concentrate indicating that the proteolytic activity in rumen reached its peak two hours post-feeding. The difference in the overall concentration of ammonia nitrogen between the two species was highly significant ($P \angle 0{\cdot}01$), the respective figures for buffalo and zebu being 8·29 and 6·31 mg.% CRL$_5$. If the higher food and protozoal nitrogen content of zebu SRL could be ascribed to greater quantity of undigested "nitrogen-fraction of the food", then this fact, when considered alongwith the data on total nitrogen and its different fractions (vide supra) permits the conclusion that compared to zebu the buffalo rumen microbes possess higher proteolytic and protein synthesizing activity.

3. *Microbial population in buffalo and zebu rumen*

Since there was no significant variation in the total bacterial and protozoal number either within species between intervals or between species within intervals (Table 5), the higher proteolytic and protein synthesizing activity of buffalo rumen microbes could be due to the presence of greater proportion of bacteria involved in protein degradation and synthesis and/or to a greater activity/bacterium.

SUMMARY

1. No significant difference was observed in the cellulolytic activity of rumen microbes of the two species (zebu and buffalo) as judged by the concentration of TVFA in rumen contents at different intervals after feeding as well as by production of TVFA *in vitro* using cellulose as substrate.

2. pH and redox potential variation in the rumen contents of the two species did not indicate any significant variation either.

3. The concentrations of bacterial and ammonia nitrogen were significantly higher in buffalo than in zebu rumen contents.

4. No significant difference was observed in the —amino and peptide nitrogen concentration in the rumen contents of two species.

5. Zebu rumen content was found to possess significantly higher concentration of food and protozoal nitrogen and the difference in all probability was due to higher quantity of undigested nitrogen of food.

6. No significant difference was observed in the total number of rumen bacteria and protozoa either between species within intervals or within species between intervals.

7. The possibility of higher proteolytic and protein synthesizing activity of buffalo rumen microbes has been discussed.

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TABLE 1

pH and Redox potential of buffalo and zebu SRL at different intervals after feeding.

Characteristics	Species	Hours after feeding			
		8 hrs.	10 hrs.	13 hrs.	15 hrs.
pH (n=15)	Buffalo	6·95±0·173	6·81±0·508	6·77±0·126	6·78±0·126
	Zebu	7·07±0·187	6·87±0·011	6·75±0·150	6·82±0·130
Redox potential (mV) (n=5)	Buffalo	—350·1±16·12	—378·9±6·10	—379·5±3·28	—364·7±9·88
	Zebu	—367·1±5·99	—369·2±8·77	—375·0±13·64	—343·8±19·82

TABLE 2

TVFA production *in vitro* from cellulose incubated with SRL of buffalo and zebu (n=7+)

Species	TVFA (mg./2 ml. GAR content)	
	24 hours	48 hours
Buffalo	0·771±0·188**	3·238±0·522
Zebu	0·517±0·339**	2·224±0·437

**Significant at 1 per cent level.

TABLE 3

Overall average of total nitrogen (mg. per cent) fractions in the rumen contents of buffalo and zebu
(n=105)

Characteristics	Species	
	Buffalo	Zebu
Total—N (SRL)	62·97±1·1886	59·95±1·2608
Food & Protozoal—N (SRL)	17 73±0·8607	21·15±0·2870
Bacterial—N (CRL_1)	16·31±0·7387	12·81±0·6353
Peptide—N (CRL_5)	20·38±0·6314	20·09±0·6012
NH_3—N (CRL_5)	8·29±0·3230	6·31±0·2791

TABLE 4

Analysis of variance of total nitrogen fractions in the rumen contents of buffalo and zebu

Components	Source of variation	d.f.	M.S.S.	'F'
Total—N	Total	209		
	Between species	1	478·10	4·27*
	Between intervals	6	1698·39	15·17**
	Residual	202	111·97	
Food & Protozoal—N	Total	209		
	Between species	1	614·91	19·01**
	Between intervals	6	295·48	9·23**
	Residual	202	32·35	
Bacterial—N	Total	209		
	Between species	1	641·90	13·49**
	Between intervals	6	129·14	2·71*
	Residual	202	47·57	
Peptide and Amino—N	Total	209		
	Between species	1	4·29	0·17NS
	Between intervals	6	568·83	23·10**
	Residual	202	24·41	
Ammonia—N	Total	209		
	Between species	1	204·91	43·13**
	Between intervals	6	173·27	36·47**
	Residual	202	4·75	

NS=Not significant
**=Significant at 1 per cent level
*=Significant at 5 per cent level

TABLE 5

Total microbial number/ml. buffalo and zebu SRL at different intervals after feeding (n=10)

Characteristics	Species	Hours after feeding			
		8 hours	10 hours	13 hours	15 hours
Bacteria	Buffalo	19×10^{9}	21×10^{9}	15×10^{9}	17×10^{9}
	Zebu	16×10	22×10^{9}	14×10^{9}	16×10^{9}
Protozoa	Buffalo	$0\cdot24\times10^{6}$	$0\cdot33\times10^{6}$	$0\cdot21\times10^{6}$	$0\cdot22\times10^{6}$
	Zebu	$0\cdot20\times10^{6}$	$0\cdot27\times10^{6}$	$0\cdot20\times10^{6}$	$0\cdot21\times10^{6}$

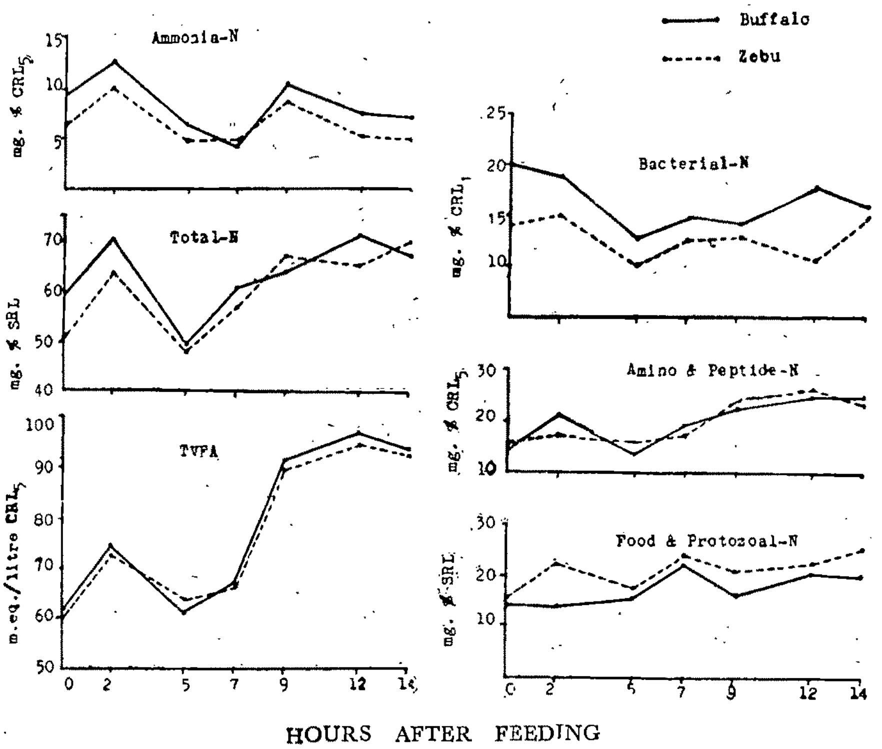

Fig. 1. Concentration of certain metabolites in the rumen contents of buffalo and zebu at different intervals after feeding.

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STUDIES ON THE EFFECT OF HIGH ENVIRONMENTAL TEMPERATURE ON THE PHYSIOLOGICAL RESPONSES OF BUFFALO

PART IV: MICRO-ANATOMY OF THE ADRENALS AND PARS INTERMEDIA AND NERVOSA OF THE PITUITARY OF BUFFALO COWS EXPOSED TO AND PROTECTED FROM SUMMER CONDITIONS.

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The reported absence of oestrus in buffaloes during hot months of the year and suppression of its symptoms during the adjacent periods are believed to be the factors responsible for the extreme seasonality of breeding in this species (Rife, 1959). Alterations in the endocrine status, which could be environment induced, have a profound effect on the reproductive physiology of animals (Nalbandev, 1958). With the above facts in view micro-anatomy of reproductive and endocrine organs was studied on buffalo cows protected from (Protected Group) and exposed to (Unprotected Group) summer climatic conditions. The present paper deals with the study on the adrenals and pars' intermedia and nervosa of the pituitary. Observations made on the reproductive organs, anterior pituitary and on the thyroid have been reported in an earlier communication of this series (Pandey and Roy, 1968).

MATERIALS AND METHODS

The details of the animals used, their housing and management under the two groups and the histological technique followed had been described earlier (Pandey and Roy, 1968).

OBSERVATIONS AND DICUSSION

Adrenals : The structure of the gland capsule in the two groups was essentially the same. In the unprotected animals the cortical tissue was broader (Fig. 1). Cells of the zona glomerulosa were larger and loosely arranged and that of the zona fasciculata were polyhedral in shape with cytoplasmic vacuolation which gave them typical spongiocytic appearance (Fig. 2). The gland tissue showed good vascularization. In contrast to above in the protected animals the cortex was narrow (Fig. 3). The zona glomerulosa cells were more compact and basophilic, appearing like rods and the intercolumnar spaces were much reduced. In zona fasciculata the shape of the cells was rather irregular and because vacuolation was not prominent the cells appeared more compact

(Fig. 4). The zona reticulosa did not show appreciable difference in the two groups. The histological picture of the adrenal cortex gives credence to the view that the gland was more active in animals exposed to the summer heat and comparatively quiescent in protected animals. The observed retention of sodium and chloride during summer by the kidneys of unprotected buffalo cows (Pandey and Roy, 1969) could have been due to the greater activity of the gland in such animals.

The adrenal medulla presented two distinct types of cellular arrangements, the peripheral and the central, as had been described by Picard and Vitry (1956) and Vitry and Picard (1956). In the unprotected animals the peripheral portion had cords of large cells with rounded nuclei and hyaline cytoplasm having peripheral chromatin granules. The cords were surrounded by sinusoidal spaces. In the central portion, a number of cell groups were visible (Fig. 5), bounded by means of connective tissue fibres. The individual cell membrane could not be distinguished and the group of cells gave a syncitial appearance. Cell nuclei were much smaller as compared to those in peripheral zone and the cytoplasm was more homogeneous. Some lymphoid tissue was also seen in the central zone. Peripheral zone in the protected animals stood out more prominently due to the compactness of cells forming the anastmosing cords. The spaces between the cords were also very prominent (Fig. 6). In the central zone the cells had glomerular arrangement and vacuolations were quite prominent. Large number of small lymphoid patches were also seen. These observations permit the interpretation that the adrenals remained inactive in the protected group. It may be reiterated here that the animals in this group were ideally housed during the day and remained throughout the summer in a condition of complete relaxation requiring little adaptive support from the adrenals. Neither had they to struggle for their food, fodder or water requirements since these were supplied at regular intervals in adequate quantities. The animals were brought outside after dark. Heat from the sandy ground surface in this arid region is lost very rapidly. The outside conditions after dusk were not stressful because of the extreme diurnal variation in the environmental temperature as evident from a maximum ranging between 105-115°F, which after sunset rapidly declined to a minimum ranging between 60-80°F.

Pituitary : In the pars intermedia there was no definite arrangement of the cells and numerous fibrous septa traversed the substance of the gland. While the cell cytoplasm in the unprotected animals showed vacuolation and nuclei in general had dense chromatin (Fig. 7), in the protected animals the cells were densely packed and had indistinct boundaries. The cytoplasm had little vacuolation and was homogeneously stained. Two types of nuclei were distinguishable, cells with oval nuclei having densely packed coarse chromatin granules and scattered in between were cells with large vesicular nuclei (one and half times the former) having less densely packed chromatin and one or two prominent nucleoli (Fig. 8). The cell cytoplasm, being vacuolated in the unprotected animal, was indicative of gland activity, its homogenicity in the protected animals tended to show that the gland tissue was less active. The pars intermedia hormone (intermedin) probably controls the melanin distribution in the animal body (Purves, 1961). One of the consistent observations made in the buffaloes was that when kept in darkened sheds the skin colour changed from the usual black to copper-brown. The histological picture of the pars intermedia suggests that this change in the skin colour can be attributed to the inactivity or subactivity of the pars intermedia when buffaloes are protected from solar radiation.

No difference could be detected in the pars nervosa of the unprotected and protected animals (Fig. 9). The architecture of the tissue resembled that described by Habel and Biberstein (1957).

SUMMARY

The micro-anatomy of the adrenals and pars' intermedia and nervosa of the pituitary was studied on buffalo cows protected from (Protected Group) and exposed to (Unprotected Group) summer climatic conditions

The size of the adrenal cortex and medulla and their histological architectures indicated greater activity of the adrenal glands in the unprotected animals and provision of adaptive support from the gland to the stress caused by the absence of shelter during the summer season.

The appearance of pars intermedia in the protected animals indicated that the gland tissue was quiescent in them, while the picture of normally active glands was evident in the unprotected animals. The subnormal activity of pars intermedia in the former strongly appeared to be associated with the change in skin colour from black to copper brown.

No difference could be detected in the pars nervosa of the unprotected and protected animals.

ACKNOWLEDGEMENT

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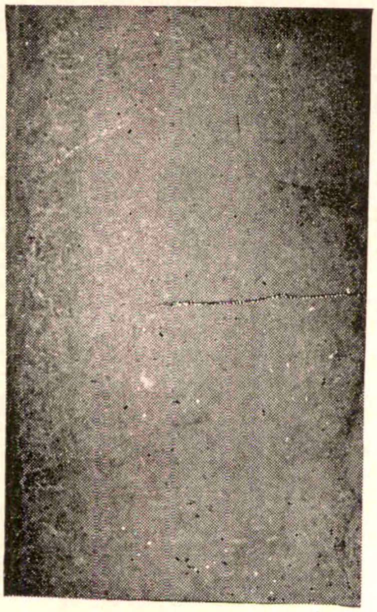


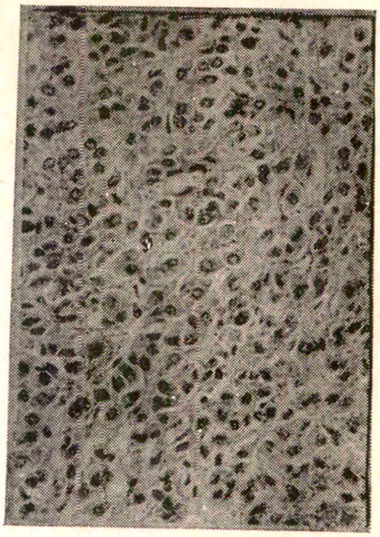
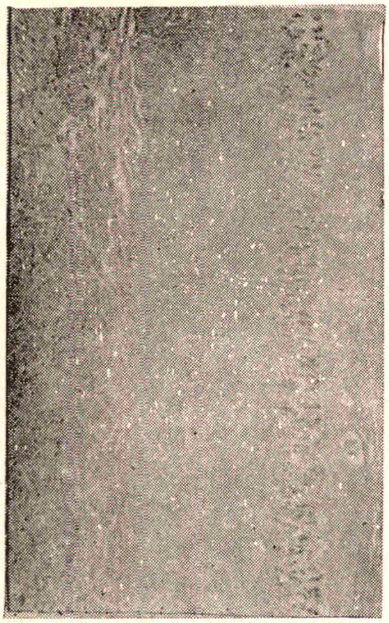


Fig. 1. Adrenal cortex of unprotected buffalo cow (x 28).
Fig. 2. Zona fasciculata of unprotected buffalo cow (x 280).



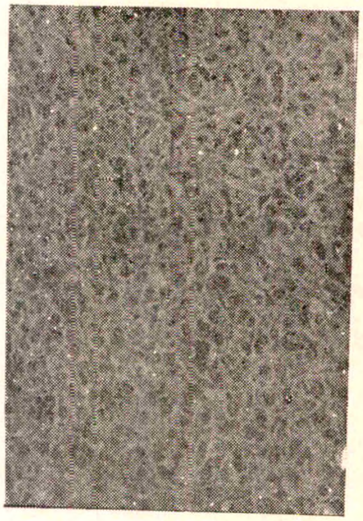
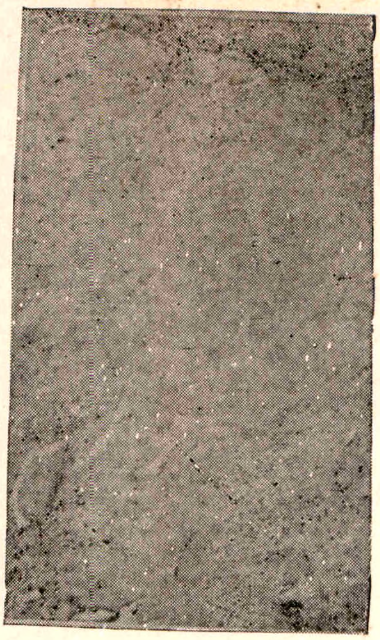


Fig. 3. Adrenal cortex of protected buffalo cow (x 28).
Fig. 4. Zona fasciculata of protected buffalo cow (x 280).



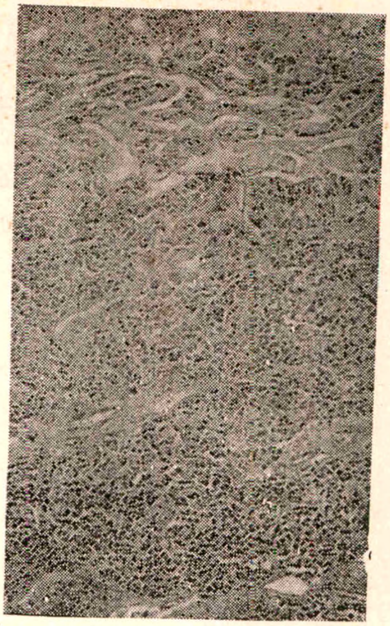
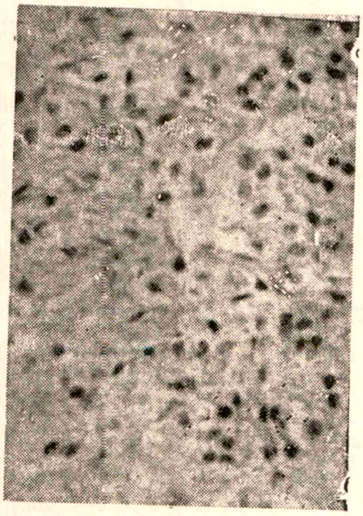


Fig. 5. Adrenal medulla of unprotected buffalo cow (x 70).
Fig. 6. Adrenal medulla of protected buffalo cow (x 70).



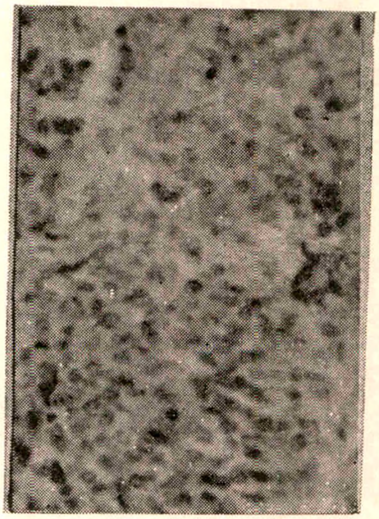


Fig. 7. Pars intermedia of unprotected buffalo cow (x 400).
Fig. 8. Pars intermedia of protected buffalo cow (x 400).

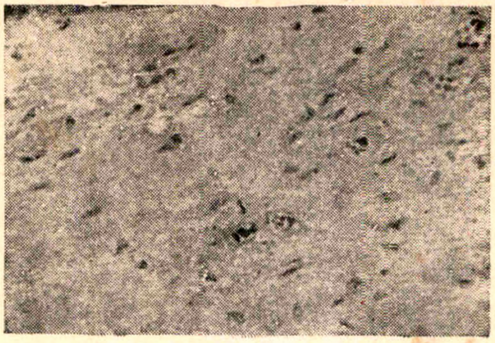


Fig. 9. Pars nervosa of buffalo cow (x 280).

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REAL INVERSION THEOREM FOR THE JOSHI GENERALIZED LAPLACE TRANSFORM

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INTRODUCTION

In some recent papers [1,2,3,4] I have given various Inversion and Representation theorems for the Joshi generalized Lapace Integral

$$(1.1)\ F(x)=\frac{\Gamma(\beta+\eta+1)}{\Gamma(\alpha+\beta+\eta+1)}\int_0^\infty (xy)^\beta {}_1F_1(\beta+\eta+1;\ \alpha+\beta+\eta+1;\ -xy) f(y)\,dy$$

$$=A\int_0^\infty (xy)^\beta {}_1F_1(a;\ b;\ -xy) f(y)\,dy$$

where for convenience we write a for $\beta+\eta+1$, b for $a+\alpha$ and A for $\frac{\Gamma(a)}{\Gamma(b)}$. In the mentioned papers I have used operators of fractional integration to develop the theorems. The object of the present paper is to give two real inversion theorems by using classical methods.

LEMMAS

In this section we give certain preliminary results which will be required in the development of the inversion theorems.

Lemma 2.1

If $a'<b'$, $o<r$

then [6]

$$I_n=\int_{a'}^{b'} e^{-nr(x-a')^2}\,dx \sim \tfrac{1}{2}\left(\frac{\pi}{nr}\right)^{\frac{1}{2}} \quad (n\to\infty)$$

Lemma 2.2

If

(*i*) $a'<a'+\xi<b'$, a' is supposed to be greater than zero.

(*ii*) $\phi(y)\ \varepsilon\ c^2\ (a'\leqslant y\leqslant a'+\xi)$

$\phi'(a')=0,\ \phi''(a')<0$

$\phi(y)$ is non increasing in $(a'\leqslant y\leqslant b')$

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then

$$(2.1) \quad \int_{a'}^{b'} e^{n\phi(y)}\, y^{\beta-a}\, dy \sim e^{n\phi(a')}\, a'^{\beta-a} \left(- \frac{\pi}{2n\phi''(a')} \right)^{\frac{1}{2}}$$

Proof

The proof follows as in Widder [6, page 277]

Lemma 2.3

If

(*i*) $a' < a' + \xi < b'$, a' is supposed to be greater than zero.

(*ii*) $\phi(y) \;\varepsilon\; c^2 \qquad (a' \leqslant y \leqslant a' + \xi)$

$\phi'(a') = 0 \;\; \phi''(a') < 0$

$\phi(y)$ is non increasing in $(a' \leqslant y \leqslant b')$

(*iii*) $\psi(y) \;\varepsilon\mathrm{L} \quad (a' \leqslant y \leqslant b'),\; \psi(a') \neq 0$

$$x(y) \equiv \int_0^y [\psi(u) - \psi(a)]\, du = 0\,(y - a') \qquad (y \to a'+)$$

then

$$(2.4) \quad \int_{a'}^{b'} \psi(y)\, e^{n\phi(y)}\, y^{\beta-a}\, dy \sim \psi(a) \cdot e^{n\phi(a')}\, a'^{\beta-a} \left(- \frac{\pi}{2n\,\phi''(a')} \right)^{\frac{1}{2}} (n \to \infty)$$

Proof

The proof follows as in Widder [6, page 278]

Theorem 2.1

If

(*i*) $f(y) \;\varepsilon\mathrm{L} \qquad (0 < x \leqslant y \leqslant \mathrm{R})$

for a fixed x and every larger R

$$(ii) \quad \int_x^\infty e^{-cy} f(y)\, dy$$

converges for a fixed positive constant c

$$(iii) \quad \int_x^y [f(u) - f(x)]\, du = 0\,(y - x) \qquad (y \to x+)$$

then

$$(2.5) \quad \frac{1}{\Gamma(\beta+n+1-a)} \left(\frac{n}{x} \right)^{\beta+n+1-a} \int_x^\infty e^{-\frac{ny}{x}}\, y^{\beta+n-a} f(y)\, dy \sim \tfrac{1}{2} f(x)$$

$(n \to \infty)$

Proof

The proof follows the lines of Widder, [6, page 280]

Theorem 2.2

If

(*i*) $f(y) \varepsilon \mathrm{L}(0<\varepsilon\leqslant y\leqslant x)$ for a fixed x and every smaller positive ε

(*ii*) $\int_{0+}^{x} y^{r} f(y)\,dy$

converges for a fixed real constant r

(*iii*) $\int_{x}^{y} [f(u)-f(x)]\,du=0\ (x-y) \qquad (y\to x-)$

then

$$(2.6)\quad \frac{1}{\Gamma(\beta-\alpha+n+1)}\left(\frac{n}{x}\right)^{\beta-\alpha+n+1}\int_{0}^{x} e^{-\frac{ny}{x}}\, y^{\beta-\alpha+n} f(y)\,dy \sim \tfrac{1}{2} f(x), \qquad (n\to\infty)$$

Proof

The proof is similar to the proof of theorem 3 *c* page 283 of Widder [3].

Theorem 2.3

If

(*i*) $f(y)\ \varepsilon\mathrm{L}\ \left(\frac{1}{\mathrm{R}}\leqslant y\leqslant \mathrm{R}\right)$ for every $\mathrm{R}>1$,

(*ii*) $\int_{1}^{\infty} f(y) e^{-cy}\,dy$

converges for a fixed $c>0$,

(*iii*) $\int_{0+}^{1} y^{r} f(y)\,dy$

converges for a fixed r,

(*iv*) $\int_{x}^{y} [f(u)-f(x)]\,du=0\ (\,|\,x-y\,|\,) \qquad (y\to x),\ x>0$

then

$$(2.7)\quad \frac{1}{\Gamma\ (\beta-\alpha+n+1}\left(\frac{n}{x}\right)^{\beta-\alpha+n+1}\int_{0+}^{\infty} e^{-\frac{ny}{x}}\, y^{+\beta-\alpha+n} f(y)\,dy \sim f(x) \qquad (n\to\infty)$$

Proof

The proof is obtained by combining the results of Theorems 2.1 and 2.2.

INVERSION OPERATOR FOR THE GENERALIZED LAPACE TRANSFORM

We now define the inversion operator which will invert the transform (1.1).

Definition 3.1

An operator $Q_{n,t}\{F(x)\}$ is defined for any real positive t and any positive integer n by the equation

$$Q_{n,t}\{F(x)\} = \frac{(-)^n}{\Gamma(n+1+\beta-\alpha)}\, x^{-\eta+1}\, D^n x^{-a}\, D^{-n}\, x^{\alpha+\beta+\eta+1}\, D^n\left[x^{-\beta}F(x)\right]\Big|_{x=\frac{n}{t}}$$

where $D^{-n}\{G(x)\}$ is a function $\psi(x)$ such that $D^n\{\psi(x)\}=G(x)$, $D^n \equiv \left(\frac{d}{dx}\right)^n$

Let us take

$$F(x,y) = \frac{\Gamma(a)}{\Gamma(b)}\,(xy)^\beta\, {}_1F_1(a, b, -xy)$$ with the notation of §1.

Now [7] $\left(\frac{d}{dx}\right)\left({}_1F_1(a;b;x)\right) = \frac{a}{b}\,{}_1F_1(a+1;b+1;x)$

and $\left(\frac{d}{dx}\right)^n\left({}_1F_1(a;b;x)\right) = \frac{\Gamma(a+n)\,\Gamma(b)}{\Gamma(b+n)\,\Gamma(a)}\,{}_1F_1(a+n;b+n;x)$

Therefore

$$\left(\frac{d}{dx}\right)^n\left[x^{-\beta}F(x,y)\right] = (-)^n\frac{\Gamma(a+n)}{\Gamma(b+n)}\,y^{\beta+n}\,{}_1F_1(a+n;b+n;-xy)$$

and

$$D^{-n}x^{a+\beta+\eta+n}\,D^n\left[x^{-\beta}F(x,y)\right] = (-)^n\frac{\Gamma(a+n)}{\Gamma(b+2n)}\,x^{b+2n-1}\,y^{\beta+n}\,{}_1F_1(a+n;b+2n;-xy)$$

since [7] $\left(\frac{d}{dx}\right)^n\left\{x^{b-1}\,{}_1F_1(a;b;x)\right\} = (-)^n(1-b)_n\,x^{b-1-n}\,{}_1F_1(a;b-n;x)$

where $(a)_n = \frac{\Gamma(a+n)}{\Gamma(a)}$

Again by using the result [7]

$$\left(\frac{d}{dx}\right)^n\left\{x^{a+n-1}\,{}_1F_1(a;b;x)\right\} = (a)_n\,x^{a-1}\,{}_1F_1(a+n;b;x)$$

we get

$$D^n x^{-a} D^{-n} x^{\alpha+\beta+\eta+n} D^n\left[x^{-\beta}F(x,y)\right]$$
$$= (-)^n\frac{\Gamma(a+2n)}{\Gamma(b+2n)}\,x^{\beta+n+\eta}\,y^{\beta+n}\,{}_1F_1(a+2n;b+2n;-xy)$$

Therefore finally

$$(3.1)\quad Q_{n,t}\,[F\,(x,y)] = \left\{ \frac{1}{\Gamma(n+1+\beta-a)}\, x^{\beta+n+1}\, y^{\beta+n}\, \frac{\Gamma\,(a+2n)}{\Gamma\,(b+2n)}\,.\; {}_1F_1\,(a+2n;\, b+2n;\, -xy) \right\}_{x=\frac{n}{t}}$$

$$= \frac{\Gamma\,(a+2n)}{\Gamma\,(b+2n)\;\Gamma\,(n+1+\beta-a)} \left(\frac{n}{t}\right)^{\beta+n+1} y^{\beta+n}\, {}_1F_1\left(a+2n;\, b+2n;\, -\frac{ny}{t}\right)$$

Theorem 3·1

If $f(y)$ εL in $0 \leqslant y \leqslant R$ for every positive R and is such that the integral (1.1) converges for some x ($=x_0$ say) then

$$(3.2)\quad \lim_{n\to\infty} Q_{n,t}\,[F\,(x)] = f\,(t)$$

for all positive t in the Lebesgue set for $f(y)$.

Proof

We have as in (3.1)

$$Q_{n,t}\left\{F\,(x)\right\} = \frac{\Gamma\,(a+2n)}{\Gamma\,(b+2n)\,\Gamma\,(n+1+\beta-a)} \left(\frac{n}{t}\right)^{\beta+n+1} \int_0^\infty y^{\beta+n}\, {}_1F_1\left(a+2n;\, b+2n;\, -\frac{ny}{t}\right) f(y)\, dy$$

Now by using a result of Slater [7]

$$\frac{\Gamma\,(a+2n)}{\Gamma\,(b+2n)}\, {}_1F_1\left(a+2n;\; b+2n;\; -\frac{ny}{t}\right) \sim \left(\frac{ny}{t}\right)^{a-b} e^{-ny/t} \quad (n\to\infty)$$

Therefore

$$Q_{n,t}\left\{F\,(x)\right\} \sim \frac{1}{\Gamma\,(n+1+\beta-a)} \left(\frac{n}{t}\right)^{\beta+n+1-a} \int_0^\infty y^{\beta+n-a}\, e^{-ny/t} f\,(y)\, dy \quad (n\to\infty)$$

Therefore by Theorem 2.3 we have

$$Q_{n,t}\,\{F\,(x)\} \sim f\,(t) \quad (n\to\infty)$$

Now to verify whether that the conditions of the theorem 2.3 are satisfied we note that $f(y)$ ε L in $(0 \leqslant y \leqslant R)$ for every positive R. Therefore r of the theorem 3.3 may be taken to be zero. Also c may be taken greater than Re x_0, since [by theorem 2.1,2] the integral

$$\int_0^\infty e^{-xu} f\,(u)\, du$$

then converges.

This completes the proof of the theorem.

THE INVERSION OPERATOR FOR THE GENERALIZED LAPLACE STIELTJES TRANSFORM

By the use of the operator $Q_{n,t}\{F(x)\}$ defined by 3.1 we can also invert the generalized Laplace-Stieltjes integral

$$(4.1)\quad F(x)=A\int_0^\infty (xy)^\beta\, {}_1F_1(a;\, b;\, -xy)\, d\psi(y)$$

where $\psi(y)$ is a normalized function of bounded variation.

Before giving an inversion theorem for this case we prove a lemma.

Lemma 4.1

If (4·1) converges then, provided that $\mathrm{Re}\,\beta\geqslant 0$, $\mathrm{Re}\,\eta>0$

$$(4.2)\quad \lim_{r\to 0+} n^{\beta+n+1}\frac{\Gamma(a+2n)}{\Gamma(b+2n)\,\Gamma(n+1+\beta-a)}\,\frac{1}{r^{n+\beta}}\int_0^\infty y^{n+\beta}\,{}_1F_1\left(a+2n;\, b+2n,\, -\frac{ny}{r}\right)\times\psi(y)\,dy$$

$$=\frac{n\,\Gamma(\beta+n)\,\Gamma(\eta+n+1)}{\Gamma(n+1+\beta-a)\,\Gamma(a+\eta+n+1)}\,\psi(0+)$$

Proof

Corresponding to an arbitrary positive ε, we determine δ such that

$$|\psi(y)-\psi(0+)|<\varepsilon\quad(0\leqslant y\leqslant\delta)$$

We then have, denoting $\dfrac{1}{\Gamma(n+1+\beta-a)}\,\dfrac{\Gamma(a+2n)}{\Gamma(b+2n)}\,n^{\beta+n+1}$ by A′,

and

$$A'\int_0^\infty\left(\frac{y}{r}\right)^{n+\beta}\frac{1}{y}\,{}_1F_1\left(a+2n;b+2n;\,-\frac{ny}{r}\right)[\psi(y)-\psi(0+)]\,dy$$

by I_r,

$$|I_r|\leqslant\left|A'\int_0^\delta y^{n+\beta-1}\,r^{-n-\beta}\,{}_1F_1\left(a+2n;b+2n;-\frac{ny}{r}\right)[\psi(y)-\psi(0+)]dy\right|$$

$$+\left|A\int_\delta^\infty y^{n+\beta-1}\,r^{-n-\beta}\,{}_1F_1\left(a+2n;\,b+2n;\,-\frac{ny}{r}\right)[\psi(y)-\psi(0+)]dy\right|\leqslant$$

$$\leqslant\left|A'\,\varepsilon\int_0^\infty y^{n+\beta-1}\,r^{-n-\beta}\,{}_1F_1\left(a+2n;\,b+2n;\,-\frac{ny}{r}\right)dy\right|+$$

$$+\left|MA'\int_\delta^\infty y^{n+\beta+\eta}\,r^{-n-\beta}\,{}_1F_1\left(a+2n;\,b+2n;-\frac{ny}{r}\right)dy\right|$$

where

$$M=\underset{\delta\leqslant y\leqslant\infty}{l.\,u.\,b.}\left|\frac{\psi(y)-\psi(0+)}{y^{\eta+1}}\right|$$

since [2] $\psi(y)=0\,(y^{\eta+1})$ where $\eta>0$ $a\neq 0$ $(y\to\infty)$, as it is given that the integral 4.1 converges.

Therefore

$$\left|I_r\right| \leqslant \varepsilon\left|\frac{n\Gamma(\beta+n)\,\Gamma(\eta+n+1)}{\Gamma(n+1+\beta-a)\,\Gamma(a+\eta+n+1)}\right| + \left|\frac{r^{n+1}}{n^{n}}\, M\, \frac{\Gamma(\beta+\eta+n+1)\,\Gamma(n+1)}{\Gamma(a+n+1)}\right|$$

Therefore $\lim\limits_{r\to 0+} I_r=0$, since ε is arbitrary and $\mathrm{Re}\,\eta>0$.

Hence we have

$$A'\int_0^\infty \left(\frac{ny}{r}\right)^{n+\beta-1}\left(\frac{n}{r}\right)^{-n-\beta+1}{}_1F_1\left(a+2n;\, b+2n;\, -\frac{ny}{r}\right)\psi(y)\,dy \sim$$

$$\sim A'\,\frac{\psi(0+)}{n^{\beta+n}}\int_0^\infty r^{\beta+n}\,t^{n+\beta-1}\;{}_1F_1(a+2n;\, b+2n;\, -t)\,dt$$

$$=\frac{n\,\Gamma(\beta+n)\,\Gamma(n+\eta+1)\,r^{\beta+n}}{\Gamma(a+\eta+n+1)\,\Gamma(n+1+\beta-a)}\,\psi(0+) \qquad (r\to 0+,\ n=2,3\ldots\ldots..)$$

This establishes the lemma.

N.B.—This is the proof when $a\neq 0$. When $a=0$ only statements change but the line of proof is similar.

Theorem 4.1

If $\psi(y)$ is a normalized function of bounded variation in $0\leqslant y\leqslant R$ for every positive R and if the integral (4.1) converges for some x, then

$$\lim_{n\to\infty}\int_{0+}^{u} Q_{n,t}\,[F(x)]\,dt=\psi(u)-\psi(0+)$$

Proof

We have as in previous section

$$Q_{n,t}\{F(x)\}=\frac{1}{\Gamma(n+1+\beta-a)}\left(\frac{n}{t}\right)^{\beta+n+1}\frac{\Gamma(a+2n)}{\Gamma(b+2n)}$$

$$\int_0^\infty y^{\beta+n}\;{}_1F_1\left(a+2n;\, b+2n;\, -\frac{ny}{t}\right)d\,\psi(y).$$

If A′ is defined as in lemma, we have,

$$Q_{n,t}\{F(x)\}=A\left[y^{\beta+n}\,t^{-\beta-n-1}\;{}_1F_1\left(a+2n;\, b+2n;\, -\frac{ny}{t}\right)\psi(y)\right]_0^\infty +$$

$$-A\int_0^\infty \psi(y)\left(\frac{\partial}{\partial y}\right)\left[y^{\beta+n}\,t^{-\beta-n-1}\;{}_1F_1\left(a+2n;\, b+2n;\, -\frac{ny}{t}\right)\right]dy$$

$$=-A\int_0^\infty \psi(y)\left(\frac{\partial}{\partial y}\right)\left[y^{\beta+n}\,t^{-\beta-n-1}\;{}_1F_1\left(a+2n;\, b+2n;-\frac{ny}{t}\right)\right]dy$$

since the integrated part vanishes.

For $\psi(0)=0,\ \psi(y)=0\,(y^{\eta+1}),\ \alpha\neq 0 \qquad (y\to\infty)$

Also [7]

$$ {}_1F_1\left(a+2n;\ b+2n;\ -\frac{ny}{t}\right)\sim y^{-a}\quad (\text{Re } a>0) \qquad (y\to\infty)$$

Again by Euler's theorem on homogeneous functions we have

$$\left(\frac{\partial}{\partial y}\right)\left[y^{\beta+n}\,t^{-\beta-n-1}\ {}_1F_1\left(a+2n;\ b+2n;\ -\frac{ny}{t}\right)\right]$$

$$=-\left(\frac{\partial}{\partial t}\right)\left[\frac{y^{\beta+n-1}}{t^{\beta+n}}\ {}_1F_1\left(a+2n; b+2n; -\frac{ny}{t}\right)\right]$$

$$Q_{n,t}\,[F(x)]=-A\int_0^\infty \frac{\psi(y)}{y}\left(\frac{\partial}{\partial t}\right)$$

$$\left\{\left(\frac{y}{t}\right)^{\beta+n}{}_1F_1\left(a+2n;\ b+2n;\ -\frac{ny}{t}\right)\right\}dy$$

If $0<\varepsilon<y$

$$\int_\varepsilon^u Q_{n,t}\{F(x)\}\,dt=A\left[\int_0^\infty \frac{\psi(y)}{y}\left(\frac{y}{t}\right)^{\beta+n}{}_1F_1\left(a+2n; b+2n; -\frac{ny}{\varepsilon}\right)dy\right.$$

$$\left.-\int_0^\infty \frac{\psi(y)}{y}\,\frac{y^{\beta+n}}{u^{\beta+n}}\ {}_1F_1\left(a+2n;\ b+2n;\ -\frac{ny}{u}\right)\times dy\right]$$

Allowing ε to approach zero and making use of lemma 4.1

we have

$$\int_{0+}^u Q_{n,t}\{F(x)\}\,dt=A\int_0^\infty \frac{\psi(y)}{y}\left(\frac{y}{t}\right)^{\beta+n}{}_1F_1\left(a+2n;\ b+2n;\ -\frac{ny}{t}\right)dy$$

$$-\psi(0+)\ \frac{n\,\Gamma(\beta+n)\,\Gamma(\eta+n+1)}{\Gamma(\alpha+\eta+n+1)\,\Gamma(n+1+\beta-\alpha)}$$

Hence if $\dfrac{\psi(y)}{(y)}=\phi(y)$ we have by the use of the theorem 3.3

$$\lim_{n\to\infty}\int_{0+}^u Q_{n,t}\{F(x)\}\,dx=u\,\phi(u)-\psi(0+)$$

$$=\psi(u)-\psi(0+)$$

This concludes the proof.

N.B.—The proof is similar when $\alpha=0$.

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INVERSION AND REPRESENTATION THEOREMS FOR A GENERALISED LAPLACE TRANSFORM BY USE OF OPERATORS OF FRACTIONAL INTEGRATION I.

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Introduction

In this paper we give inversion and representation theorems, by the use of operators of fractional integration introduced by Kober-Erdelyi, for the transform.

$$f(s)=2^{-\nu/2}\int_0^{\infty}(st)^{\lambda}\,e^{-\frac{1}{2}st}\,D_{\nu}(\sqrt{2st})\,\phi(t)\,dt \qquad ..(1.1)$$

where $D_\nu(z)$ is parabolic cylinder function.

For $\lambda=\nu=0$, (1.1) reduces to Laplace Transform

$$f(s)=\int_0^{\infty}e^{-st}\,\phi(t)\,dt$$

Kober (1940) defined the operators of fractional integration in the form

$$I^{+}_{\eta,\alpha}f(s)=\frac{s^{-\eta-\alpha}}{\Gamma(\alpha)}\int_0^{s}(s-t)^{\alpha-1}\,t^{\eta}f(t)\,dt \qquad ..(1.2)$$

$$\bar{K}_{\rho,\alpha}f(s)=\frac{s^{\rho}}{\Gamma(\alpha)}\int_s^{\infty}(t-s)^{\alpha-1}\,t^{-\rho-\alpha}f(t)\,dt \qquad ..(1.3)$$

where $f(s)\ \varepsilon\ L_p\,(0,\infty)$, $\frac{1}{p}+\frac{1}{q}=1$ if $1\angle p\angle\infty$, and $\frac{1}{q}$ or $\frac{1}{p}=0$ if p or $q=1$, $\alpha>0$, $n>-\frac{1}{q}$, $\rho>-\frac{1}{p}$.

If $\alpha<0$, $g(s)=I^{+}_{\eta,\alpha}f(s)$ and $h(s)=K^{-}_{\rho,\alpha}f(s)$

are defined as the solutions (if any) of the integral equations

$$f(s)=I^{+}_{\eta+\alpha,\,-\alpha}\,g(s),\quad f(s)=K^{-}_{\rho+\alpha,\,-\alpha}\,h(s)$$

The Mellin transform of a function $f(s) \in L_p(0, \infty)$ is defined as

$$\phi(t) = \bar{M}_t f(s) = \int_0^{\infty} f(s)\, s^{it}\, ds \quad (p=1) \qquad ..(1.4)$$

and

$$= \underset{S\to\infty}{\overset{(q)}{\text{l.i.m.}}} \int_{-S}^{S} f(s)\, s^{it-1/q}\, ds \qquad (p>1)$$

The inverse Mellin transform $M^{-1}\phi(t)$ of a function $\phi(t) \in L_q(-\infty, \infty)$ is defined as

$$f(s) = M^{-1}{}_t\, \phi(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \phi(t)\, s^{-it}\, dt \qquad (q=1) \qquad ..(1.5)$$

$$= \frac{1}{2\pi} \underset{T\to\infty}{\overset{(p)}{\text{l.i.m.}}} \int_{-T}^{T} \phi(t)\, s^{-it-1/p}\, dt \qquad (q>1)$$

where $\overset{(p)}{\text{l.i.m.}}$ indicates the limit in mean with index p over the interval $(0, \infty)$.

If the Mellin transform is applied to the definitions of the Kober's operators and the orders of integration are interchanged we obtain under certain conditions

$$\bar{M}_t\left[\overset{+}{I}_{\eta,\alpha} f(s)\right] = \frac{\Gamma\left(\eta + \frac{1}{q} - it\right)}{\Gamma\left(\alpha + \eta + \frac{1}{q} - it\right)}\, \bar{M}_t f(s) \qquad ..(1.6)$$

and

$$\bar{M}_t\left[K^{-}_{\rho,\,\alpha} f(s)\right] = \frac{\Gamma\left(\rho + \frac{1}{p} + it\right)}{\Gamma\left(\alpha + \rho + \frac{1}{p} + it\right)}\, \bar{M}_t f(s) \qquad ..(1.7)$$

But

$$\bar{M}_t\left(s^{\beta} e^{-s}\right) = \int_0^{\infty} e^{-s} s^{\beta - 1/q + it}\, ds$$

$$= \Gamma\left(\beta + \frac{1}{p} + it\right)$$

if Re. $\beta > -\frac{1}{q}$.

Therefore

$$\bar{M}_t\left[\overset{+}{I}_{\eta,\,\alpha}\left(s^{\beta} e^{-s}\right)\right] = \frac{\Gamma\left(\eta + \frac{1}{q} - it\right)\ \Gamma\left(\beta + \frac{1}{p} + it\right)}{\Gamma\left(\alpha + \eta + \frac{1}{q} - it\right)} \qquad ..(1.8)$$

and

$$\bar{M}_t \left| K^-_{\rho,\,\alpha}\left(s^{\beta}e^{-s}\right)\right| = \frac{\Gamma(\rho+\frac{1}{p}+it)\,\Gamma(\beta+\frac{1}{p}+it)}{\Gamma(\alpha+\rho+\frac{1}{p}+it)} \qquad ..(1.9)$$

Hence by (1.5) we have

$$I^+_{\eta,\,\alpha}\left(s^{\beta}e^{-s}\right) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{\Gamma(\eta+\frac{1}{q}-it)\,\Gamma(\beta+\frac{1}{p}+it)}{\Gamma(\alpha+\eta+\frac{1}{q}-it)}\, s^{-it-\frac{1}{p}}\,dt \qquad ..(1.10)$$

and

$$K^-_{\rho,\,\alpha}\left(s^{\beta}e^{-s}\right) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{\Gamma(\rho+\frac{1}{p}+it)\,\Gamma(\beta+\frac{1}{p}+it)}{\Gamma(\alpha+\rho+\frac{1}{p}+it)}\, s^{-it-\frac{1}{p}}\,dt \qquad ..(1.11)$$

provided that Re. $\beta > -\frac{1}{p}$, Re. $\rho > -\frac{1}{p}$, Re. $\eta > -\frac{1}{q}$, $-\frac{\pi}{2} \angle \arg. s \angle \frac{\pi}{2}$.

If this integral (1.11) is evaluated by calculus of residues we get

$$K^-_{\rho,\,\alpha}\left(s^{\beta}e^{-s}\right) = s^{\beta}\sum_{n=0}^{\infty}\frac{\Gamma(\rho-\beta-n)}{\Gamma(\alpha+\rho-\beta-n)}\cdot\frac{(-s)^n}{n!} + s^{\rho}\sum_{n=0}^{\infty}\frac{\Gamma(\beta-\rho-n)}{\Gamma(\alpha-n)}\cdot\frac{(-s)^n}{n!} \qquad ..(1.12)$$

Also from definition we get

$$K^-_{\rho,\,\alpha}\left(s^{\lambda}e^{-s}\right) = \frac{s^{\rho}}{\Gamma(\alpha)}\int_{s}^{\infty}(t-s)^{\alpha-1}\,t^{-\rho-\alpha+\lambda}\,e^{-t}\,dt \qquad ..(1.13)$$

which is convergent if Re. $\alpha>0$ and $s>0$ (s being real)

In particular

$$K^-_{\lambda+\frac{1}{2},\,-\frac{\nu}{2}}\left[s^{\lambda}e^{-s}\right] = 2^{-\nu/2}\,s^{\lambda}\,e^{-\frac{1}{2}s}\,D_{\nu}(\sqrt{2s}) \qquad ..(1.14)$$

The integral represented by $K^-_{\lambda+\frac{1}{2},\,-\frac{\nu}{2}}\left[s^{\lambda}e^{-s}\right]$ exists if $\nu<0$, $\lambda>-\frac{1}{p}$ and $s>0$.

If $\nu>0$,

$$K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\,\frac{\nu}{2}}\left[2^{-\nu/2}\,s^{\lambda}\,e^{-\frac{1}{2}s}\,D_{\nu}(\sqrt{2s})\right]$$

$$= \frac{s^{\lambda-\nu/2+\frac{1}{2}}}{\Gamma\left(\frac{\nu}{2}\right)} \int_s^\infty (t-s)^{\nu/2-1}\, t^{-\frac{1}{2}}\, e^{-\frac{1}{2}t}\, D\nu\,(\sqrt{2t})\, dt$$

$$= s^\lambda e^{-s}$$

where $s>0$, $\lambda+\frac{1}{2}-\frac{\nu}{2} > -\frac{1}{p}$ and so (1.14) still holds.

THE FUNCTIONAL TRANSFORMATION

In this section we prove a theorem which establishes relation between the integral (1.1) and the transform

$$F\,(s) = \int_0^\infty (st)^\lambda\, e^{-st}\, \phi\,(t)\, dt \qquad ..(2.1)$$

Theorem 2.1

If

(i) $\phi\,(t) \in L_p\,(0,\, \infty)$, $1 \leqslant p \angle \infty$, $s>0$

(ii) $\lambda > -\frac{1}{q}$ when $\nu \angle 0$ and $\lambda+\frac{1}{2}-\frac{\nu}{2} > -\frac{1}{q}$ when $\nu>0$; then

$K^-_{\lambda+\frac{1}{2},\, -\nu/2}\,[F\,(s)]$ exists and is equal to $f\,(s)$ where $f\,(s)$ and $F\,(s)$ are given by (1.1) and (2.1) respectively.

Proof:—

Case I $\nu \angle 0$, $1 \angle p \angle \infty$

If $\phi\,(t) \in L_p\,(0, \infty)$, $1 \leqslant p \angle \infty$ and $s>0$ it is easy to see that $F\,(s)$ exists under the conditions of the theorem.

Therefore

$$K^-_{\lambda+\frac{1}{2},\, -\nu/2}\,[F\,(s)] = \frac{s^{\lambda+\frac{1}{2}}}{\Gamma\left(-\frac{\nu}{2}\right)} \int_s^\infty (x-s)^{-\nu/2-1}\, x^{\nu/2-\frac{1}{2}-\lambda}\, F(x) dx$$

$$= \frac{s^{\lambda+\frac{1}{2}}}{\Gamma\left(-\frac{\nu}{2}\right)} \int_s^\infty (x-s)^{-\frac{\nu}{2}-1}\, x^{\frac{\nu}{2}-\lambda-\frac{1}{2}}$$

$$\left[\int_0^\infty (xt)^\lambda\, e^{-xt}\, \phi\,(t)\, dt\right] dx$$

$$= \frac{s^{\lambda+\frac{1}{2}}}{\Gamma\left(-\frac{\nu}{2}\right)} \int_s^{\infty} t^{\lambda} \phi(t) \left[\int_s^{\infty} (x-s)^{-\frac{\nu}{2}-1} s^{\frac{\nu}{2}-\frac{1}{2}} e^{-tx} \, dx \right] dt$$

changing the order of integration which will be justified later. Hence

$$K^{-}_{\lambda+\frac{1}{2}, -\frac{\nu}{2}} [F(s)] = 2^{-\nu/2} \int_0^{\infty} (st)^{\lambda} e^{-\frac{1}{2}st} D\nu(\sqrt{2st}) \phi(t) \, dt$$

$$= f(s)$$

(provided Re. $\nu \angle 0$, $s > 0$)

Since Erdélyi etc. (1954, p. 202)

$$\int_s^{\infty} (x-s)^{-\nu/2-1} s^{\nu/2-\frac{1}{2}} e^{-tx} \, dx = \Gamma\left(-\frac{\nu}{2}\right). \; 2^{-\nu/2} s^{-\frac{1}{2}} e^{-\frac{1}{2}st} D\nu(\sqrt{2st})$$

(provided Re. $\nu \angle 0$, Re. $(st) > 0$).

To justify the order of integration change we have from a result due to Hardy (1933) that if

$$\left.\begin{aligned} &F(x) = \int_0^{\infty} K(x,t) \phi(t) \, dt \\ &\text{then} \quad \int_0^{\infty} x^{p-2} [F(x)]^p \, dx \angle \left[\psi\left(\frac{1}{q}\right) \right]^p \int_0^{\infty} [\phi(t)]^p \, dt \\ &\text{where} \quad \psi(r) = \int_0^{\infty} x^{r-1} K(x) \, dx. \end{aligned}\right\} \quad ..(2.2)$$

If $K(x) = x^{\lambda} e^{-x}$

$$\text{then } \psi(r) = \int_0^{\infty} x^{\lambda+r-1} e^{-x} \, dx$$

$$= \Gamma(\lambda + r)$$

(provided $\lambda + r > 0$)

Therefore

$$\int_0^{\infty} x^{p-2} [F(x)]^p \, dx \angle \left[\Gamma\left(\lambda + \frac{1}{q}\right) \right]^p \int_0^{\infty} [\phi(t)]^p \, dt$$

$$\left(\text{provided } \lambda > -\frac{1}{q}\right) \quad ..(2.3)$$

Hence if $\phi(t) \, \varepsilon \, L_p(0, \infty)$, $1 \angle p \angle \infty$, then

$$x^{1-2/p} F(x) \, \varepsilon \, L_p(0, \infty) \quad \text{and} \quad (x-s)^{\alpha} x^{\beta} F(x) \, \varepsilon \, L_p(0, \infty)$$

provided that $\alpha + \beta = 1 - \frac{2}{p}$ and $\alpha > -\frac{1}{p}$.

Therefore the integral

$$\int_s^{\infty} (x-s)^{-\nu/2-1}\, x^{\nu/2-\frac{1}{2}-\lambda}\, F(x)\, dx$$

$$=\int_s^{\infty} \left[(x-s)^{-\nu/2-1-\alpha}\, x^{\nu/2-\frac{1}{2}-\lambda-\beta} \right] [(x-s)^{\alpha}.\ x^{\beta} F(x)]\, dx \quad ..(2{\cdot}4)$$

will exist if the expressions within the brackets in the integrand belong to $L_q\,(s, \infty)$ and $L_p\,(s, \infty)$ respectively.

The conditions for these are

$$-\frac{\nu}{2}-1-\alpha > -\frac{1}{q},\ -\frac{3}{2}-\lambda-\alpha-\beta \angle -\frac{1}{q} \text{ and } \alpha+\beta=1-\frac{2}{p},\ \alpha > -\frac{1}{p}$$

These conditions reduce to $\lambda+\frac{1}{2} > -\frac{1}{q},\ \nu \angle 0.$

Hence under the conditions of the theorem $(\lambda > -\frac{1}{q},\ \nu < 0)$ the integral (2.4) converges absolutely and hence the change in the order of integration is justified.

If $p=1$, it is similarly seen that the change in the order of integration is justified if $\lambda > 0$, $\nu < 0$.

Case II $\nu > 0,\ 1 < p < \infty$

We know that if $\alpha < 0$ then the operator

$$f(s) = K^{-}_{\rho,\,\alpha}\,[F(s)]$$

is defined as the solution (if any) of the integral equation

$$F(s) = K^{-}_{\rho+\alpha,\,-\alpha}\,[f(s)]$$

Now

$$K^{-}_{\lambda+\frac{1}{2}-\frac{\nu}{2},\,\frac{\nu}{2}}\,[f(s)] = \frac{s^{\lambda+\frac{1}{2}-\frac{\nu}{2}}}{\Gamma\left(\frac{\nu}{2}\right)} \int_s^{\infty} (x-s)^{\frac{\nu}{2}-1}\, x^{-\lambda-\frac{1}{2}}\, f(x)\, dx$$

$$= \frac{s^{\lambda+\frac{1}{2}-\frac{\nu}{2}}}{\Gamma\left(\frac{\nu}{2}\right)} \int_s^{\infty} (x-s)^{\frac{\nu}{2}-1}\, x^{-\lambda-\frac{1}{2}}$$

$$\left[2^{-\frac{\nu}{2}} \int_0^{\infty} (xt)^{\lambda}\, e^{-\frac{1}{2}xt}\, D_{\nu}\,(\sqrt{2\,xt})\ \phi\,(t)\, dt \right] dx$$

On changing the order of integration which is justified we have.

$$K^{-}_{\lambda+\frac{1}{2}-\frac{\nu}{2},\,\frac{\nu}{2}}\,[f(s)] = \frac{s^{\lambda+\frac{1}{2}-\frac{\nu}{2}}}{\Gamma\left(\frac{\nu}{2}\right)}\,.\,2^{-\frac{\nu}{2}} \times$$

$$\times \int_s^{\infty} t^{\lambda} \phi(t) \left\{ \int_s^{\infty} (x-s)^{\nu/2-1} x^{-\frac{1}{2}} e^{-\frac{1}{2}xt} \, D\nu\, (\sqrt{2\,tx})\, dx \right\} dt$$

$$= \int_0^{\infty} (st)^{\lambda} e^{-st} \phi(t)\, dt$$

$$= F(s)$$

(provided $\nu > 0$)

since Erdelyi etc. (1954, *p.* 211)

$$\frac{2^{-\nu/2}}{\Gamma\left(\frac{\nu}{2}\right)} \int_s^{\infty} (x-s)^{\nu/2-1} x^{-\frac{1}{2}} e^{-\frac{1}{2}xt} \, D\nu(\sqrt{2\,xt})\, dx = s^{\nu/2-\frac{1}{2}} e^{-st}$$

(provided $\nu > 0$)

To justify the change in the order of integration we have as in case I from (2.4)

if $K(x) = 2^{-\nu/2} x^{\lambda} e^{-\frac{1}{2}x} D\nu\, (\sqrt{2\,x})$, then Goldstein (1932)

$$\psi(r) = 2^{-\nu/2} \int_0^{\infty} x^{\lambda+r-1} e^{-\frac{1}{2}x} D\nu\, (\sqrt{2\,x})\, dx$$

$$= \frac{\Gamma(\lambda+r)\, \Gamma(\lambda+r+\frac{1}{2})}{\Gamma\left(\lambda+r+\frac{1}{2}-\frac{\nu}{2}\right)}$$

(provided $\lambda + r > 0$).

Therefore

$$\int_0^{\infty} x^{p-2} [F(x)]^p \, dx = \left[\frac{\Gamma\left(\lambda+\frac{1}{q}\right) \Gamma\left(\lambda+\frac{1}{2}+\frac{1}{q}\right)}{\Gamma\left(\lambda+\frac{1}{2}+\frac{1}{q}-\frac{\nu}{2}\right)} \right]^p \int_0^{\infty} [\phi(t)]^p \, dt$$

$\left(\text{provided } \lambda > -\frac{1}{q}\right)$

Now since $\phi(t) \;\varepsilon\; L_p(0, \infty)$, $p > 1$, $x^{1-\frac{2}{p}} f(x) \;\varepsilon\; L_p(0, \infty)$

and hence

$$(x-s)^{\alpha} x^{\beta} f(x) \;\varepsilon\; L_p(s, \infty)$$

if $\alpha + \beta = 1 - \frac{2}{p}$, $\alpha > -\frac{1}{p}$.

Also

$$(x-s)^{\frac{\nu}{2}-\alpha-1} x^{-\lambda-\frac{1}{2}-\beta} \;\varepsilon\; L_q(s, \infty) \text{ if } \frac{\nu}{2}-\alpha-1 > -\frac{1}{q},$$

and

$$\frac{\nu}{2} - \frac{3}{2} - \lambda - \alpha - \beta < -\frac{1}{q}$$

These four conditions reduce to

$$\lambda+\tfrac{1}{2}-\frac{\nu}{2}>-\frac{1}{q},\ \nu>0 \qquad ..(2.5)$$

Hence under the conditions of the theorem the integral

$$\int_s^{\infty}(x-s)^{\frac{\nu}{2}-1}\,x^{-\lambda-\frac{1}{2}}f(x)\cdot dx$$

exists and is absolutely convergent. Thus the change in the order of integration is justified.

If $p=1$ the change in the order of integration is justified if $\lambda>0$, $\nu>0$.

INVERSION AND REPRESENTATION THEOREMS

In this section we give inversion and representation theorems for the transform (1.1) using an operator defined below.

Definition

An operator $W_{n,x}[g(s)]$ is defined for any positive number x and any positive integer n by the relations

$$V_0[g(s)]=g(s)$$

$$V_n[g(s)]=(-1)^n s^{\lambda+n+1}\left(\frac{d}{ds}\right)^n[s^{-\lambda}g(s)]_{n=1,2,3,\ldots}$$

$$W_{n,x}[g(s)]=\frac{1}{\Gamma(\lambda+n+1)}\Big[V_n\{g(s)\}\Big]_{s=\frac{n}{x}} \qquad ..(3.1)$$

Now we give following Lemma due to Saksena (1958)

Lemma 3.1

If $\phi(x)\ \varepsilon\ L_p$ in $(0\leqslant x<\infty)$

and $\psi(v)=\int_0^{\infty}\left|\phi(x\,v)-\phi(x)\right|^p dx$

then

(i) $\left|\frac{v\,\psi(v)}{1+v}\right|\leqslant\|\phi\|_p$ for $\nu\geqslant 0$

and (ii) $\psi(v)\to 0$ as $v\to 1$

where $\|\phi\|_p$ denotes the norm of the function $\phi(x)\ \varepsilon\ L_p\ (0,\infty)$

i.e. $\|\phi\|_p=\left[\int_0^{\infty}|\phi(x)|^p\,dx\right]^{\frac{1}{p}}$

Theorem 3.1

If

(i) $\phi(t)\ \varepsilon\ L_p\ (1\leqslant p<\infty)$ in $0\leqslant t<R$ for every positive R,

(ii) $\int_0^\infty (st)^\lambda e^{-st} \phi(t)\, dt$ converges for $s>0$

(iii) $\lambda > -\frac{1}{q}$ when $\nu<0$, and $\lambda+\frac{1}{2}-\frac{\nu}{2} > -\frac{1}{q}$ when $\nu>0$

then

$$\underset{n\to\infty}{\overset{(p)}{\text{l.i.m.}}}\ W_{n,x}\left[K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\frac{\nu}{2}}\{f(s)\}\right]=\phi(x) \qquad ..(3.2)$$

for almost all positive x.

Proof:—

We have seen in the proof of theorem 2.1 that, under the conditions of the theorem

$$K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\frac{\nu}{2}}[f(s)] = \int_0^\infty (st)^\lambda e^{-st} \phi(t)\, dt = F(s)$$

Therefore

$$V_n\left[K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\frac{\nu}{2}}\{f(s)\}\right] = s^{\lambda+n+1} \int_0^\infty t^{\lambda+n} e^{-st} \phi(t)\, dt$$

and

$$W_{n,x} \equiv W_{n,}\left[K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\frac{\nu}{2}}\{f(s)\}\right]$$

$$= \frac{n^{\lambda+n+1}}{\Gamma(\lambda+n+1)} \int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}} e^{-\frac{n}{x}t} \phi(t)\, dt$$

Hence writing A for $\frac{n^{\lambda+n+1}}{\Gamma(\lambda+n+1)}$ we have

$$\left| W_{n,x} - \phi(x) \right| \leqslant A \int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}} e^{-\frac{n}{x}t} \left| \phi(t) - \phi(x) \right| dt$$

$$= A \int_0^\infty v^{\lambda+n} e^{-nv} \left| \phi(xv) - \phi(x) \right| dv$$

and

$$\left| W_{n,x} - \phi(x) \right|^p \leqslant \left| A \int_0^\infty v^{\lambda+n} e^{-nv} \left| \phi(vx) - \phi(x) \right| dv \right|^p$$

$$\leqslant \left[A \int_0^\infty v^{\lambda+n} e^{-nv} \left| \phi(xv) - \phi(x) \right|^p dv \right] \times$$

$$\times \left[A \int_0^\infty e^{-nv} v^{\lambda+n}\, dv \right]^{p/q}$$

$$= A \int_0^\infty v^{\lambda+n} e^{-nv} \left| \phi(vx) - \phi(x) \right|^p dv$$

Hence

$$\int_C^\infty \left| W_{n,x} - \phi(x) \right|^p dx \leqslant A \int_0^\infty dx \int_0^\infty v^{\lambda+n} v^{-nv}$$

$$\left| \phi(xv) - \phi(x) \right|^p dt \qquad \ldots(3.3)$$

$$= A \int_0^\infty v^{\lambda+n} e^{-nv} \left[\int_0^\infty \phi(xv) - \phi(x) \right|^p dx \Bigg] dv$$

$$\leqslant A \int_0^\infty v^{\lambda+n} e^{-nv} \psi(v)\, dv$$

on changing the order of integration, where

$$\psi(v) = \int_0^\infty \left| \phi(xv) - \phi(x) \right|^p dx$$

From Lemma 3.1

$$\psi(v) = O(1),\ v \to \infty$$
$$= O(v^{-1})\ v \to 0+$$

Therefore the right hand side of inequality (3.3) converges under given conditions and the inversion of order of integration is justified by Fubinis theorem.

Hence by Theorem 5.2.3 (Tivari, 1967) the right hand side of (3.3) approaches $\psi(1)$ as n tends to infinity and by Lemma 3.1

$$\lim_{v \to 1} \psi(v) = O(1)$$

Therefore $W_{n,x}$ converges in mean to $\phi(x)$ with index p on $0 \leqslant x < \infty$ and the result is proved.

Theorem 3.2

The necessary and sufficient condition for a function $f(s)$ to have the representation (1.1) with

$\phi(t) \in L_p(0, \infty), p \geqslant 1, s > 0$ and with $\lambda > -\frac{1}{q}$ when $\nu < 0$ and

$\lambda + \frac{1}{2} - \frac{\nu}{2} > -\frac{1}{q}$ when $\nu > 0$; are

(i) $K^{-1}_{\lambda+\frac{1}{2}-\frac{\nu}{2}, \frac{\nu}{2}} [f(s)] = G(s)$ exists and has derivatives of all orders in $0 < s < \infty$ and vanishes at infinity,

(ii) there exist constants M and p $(p \geqslant 1)$ such that

$$\int_0^\infty \left| W_{n,x} [G(s)] \right|^p dx < M, \ (n = 1, 2, 3, \ldots)$$

Proof:—

First let $f(s)$ has the representation (1.1) then from theorem (2.1)

$$G(s) = K^{-}_{\lambda+\frac{1}{2}-\frac{\nu}{2},\frac{\nu}{2}}[f(s)] = F(s)$$

Under the conditions of the theorem it is clear that $F(s)$ and its all derivatives exist, for by Holder's inequality

$$\int_0^\infty (st)^\lambda e^{-st}\,|\phi(t)|\,dt \leqslant \left[\int_0^\infty |\phi(t)|^p\,dt\right]^{\frac{1}{p}}$$

$$\left[\int_0^\infty e^{-qst}(st)^{\lambda q}\,dt\right]^{\frac{1}{q}} \quad \text{where } s>0,\ \lambda>-\frac{1}{q}.$$

The integral on the right of this inequality exists since we have assumed that $\phi(t) \varepsilon L_p(0, \infty)$. Thus $F(s)$ converges absolutely.

Also

$$\begin{aligned} F(s) &\sim \int_0^\infty (st)^\lambda e^{-st}\phi(t)\,dt \\ &\leqslant M' \int_0^\infty (st)^\lambda e^{-st}\,dt \\ &= \frac{M'}{s}\,\Gamma(\lambda+1) \\ &= 0(1) \end{aligned}$$

as $s \rightarrow \infty$ (since $\phi(t)$ is bounded)

Hence the necessity of condition (i) is established.

Again by Holder's inequality

$$\left|W_{n,x}[G(s)]\right|^p = \left|A\int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}}\,e^{-\frac{n}{x}t}\,\phi(t)\,dt\right|^p$$

$$\leqslant \left[A\int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}}\,e^{-\frac{n}{x}t}\,|\phi(t)|^p\,dt\right] \times$$

$$\times \left[A\int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}}\,e^{-\frac{n}{x}t}\,dt\right]^{\frac{p}{q}}$$

$$= A\int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}}\,e^{-\frac{n}{x}t}\,|\phi(t)|^p\,dt$$

Therefore

$$\int_0^\infty \left| W_{n,x}\,[G\,(s)] \right|^p dx \leqslant \int_0^\infty dx\, A \int_0^\infty \frac{t^{\lambda+n}}{x^{\lambda+n+1}}\, e^{-\frac{n}{x}t} \left| \phi\,(t) \right|^p dt$$

$$\doteq \int_0^\infty \frac{t^{\lambda+n}}{\Gamma\,(\lambda+n+1)} \left| \phi\,(t) \right|^p dt \int_0^\infty \left(\frac{n}{x} \right)^{\lambda+n+1} e^{-\frac{n}{x}t}\, dx \quad ..(3.4)$$

On changing the order of integration, which is justified, the right hand side of the inequality (3.4) converges for it is equal to

$$\int_0^\infty \left| \phi\,(t) \right|^p dt$$

which is a constant say M. This establishes the necessity of condition (ii).

Conversely let the conditions be satisfied. By Holder's inequality

$$\int_0^t \left| W_{n,x}\,[F\,(s)] \right| dx = \int_0^t \left| \int_0^\infty A\, \frac{t^{\lambda+n}}{x^{\lambda+n+1}}\, e^{-\frac{n}{x}t}\, \phi\,(t)\, dt \right| dx$$

$$\leqslant \int_0^t \left[\left\{ \int_0^\infty \left| \phi\,(t) \right|^p dt \right\}^{\frac{1}{p}} \right.$$

$$\left. \left\{ \frac{A^q}{x^{q\,(\lambda+n+1)}} \int_0^\infty t^{q\,(\lambda+n)}\, e^{-\frac{nq}{x}t}\, dt \right\}^{\frac{1}{q}} \right] dx$$

$$\leqslant M^{1/p} \int_0^t x^{-\frac{1}{p}}\, dx \qquad p \geqslant 1$$

$$\leqslant M^{1/p}\, t^{\frac{1}{q}} \qquad (n=1,2,3,\ldots)$$

Hence for each positive integer

$$\int_0^t W_{n,x}\,[F\,(s)]\, dx = 0\,(t) \qquad t \to \infty$$

Therefore as in the proof of theorem 11 (b) Widder (1941, p. 305) we see that F (∞) exists and

$$\lim_{n\to\infty} \int_0^\infty (st)^\lambda\, e^{-st}\, W_{n,t}\,[F\,(s)]\, dt = F\,(s) - F\,(\infty) \qquad (0 < s < \infty)$$

But F $(\infty) = 0$ by our hypothesis.

Now by theorem 17a Widder (1941, p. 33) there exists a sequence $\left\{ n_i \right\}_0^\infty$ of the positive integers n and a function $\phi\,(t)$ of class L_p in $(0 \leqslant t < \infty)$ such that

$$\lim_{i\to\infty} \int_0^\infty (st)^\lambda e^{-st} W_{\tilde{n}_i,t}[F(s)]\,dt$$

$$= \int_0^\infty (st)^\lambda e^{-st} \phi(t)\,dt = F(s).$$

Hence Erdélyi (1940)

$$f(s) = \left[K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\,\frac{\nu}{2}}\right]^{-1} F(s) = K^-_{\lambda+\frac{1}{2},\,-\frac{\nu}{2}}[F(s)]$$

$$= 2^{-\frac{\nu}{2}} \int_0^\infty (st)^\lambda e^{-\frac{1}{2}st} D_\nu(\sqrt{2st})\,\phi(t)\,dt \text{ ,}$$

(by theorem 2.1)

Hence the theorem.

Theorem 3.3

If $f(s)$ has the representation (1.1) with the conditions $\phi(t) \in L_p(0, \infty)$, $p \geqslant 1$, $s>0$; and $\lambda > -\frac{1}{q}$ when $\nu<0$ and $\lambda+\frac{1}{2}-\frac{\nu}{2} > -\frac{1}{q}$ when $\nu>0$; and if the fractional derivatives or integrals

$$K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2},\,\frac{\nu}{2}}[f(s)] = G(s) \qquad \text{exist then}$$

$$\lim_{n\to\infty} \int_0^\infty \left| W_{n,x}[G(s)] \right|^p dx \leqq \int_0^\infty \left| \phi(t) \right|^p dt \qquad ..(3.5)$$

Proof:—

From theorem 3.2 we have

$$\lim_{n\to\infty} \int_0^\infty \left| W_{n,x}[G(s)] \right|^p dx \leqslant \int_0^\infty \left| \phi(t) \right|^p dt$$

Also by Fatous Lemma (Titchmarsh 1932, p. 346)

$$\int_0^\infty \left| \phi(t) \right|^p dt \leqslant \underline{\lim}_{n\to\infty} \int_0^\infty \left| W_{n,x}[G(s)] \right|^p dx$$

Hence the result.

Corollary

If the fractional derivatives or integrals

$K^-_{\lambda+\frac{1}{2}-\frac{\nu}{2}+r,\,\frac{\nu}{2}-r}[f(s)]$ exist for $r=0,1,2,\ldots.$ then the expression

$$\lim_{n\to\infty} \int_0^\infty \left| W_{n,x}[F(s)] \right|^p dx$$

of theorems 3.2 and 3.3 can be replaced by

$$\int_0^\infty \left| \frac{\left(\frac{n}{x}\right)}{\Gamma(\lambda+n+1)} \sum_0^n A_r K^-_{\lambda+\frac12-\frac{\nu}{2},\,\frac{\nu}{2}}\left[f\left(\frac{n}{x}\right)\right]\right|^p dx \quad ..(3.6)$$

where

$$A_r = {}^nC_r\left(\frac{\nu}{2}-\frac12\right)\left(\frac{\nu}{2}+\frac12\right)\cdots\cdots\left(\frac{\nu}{2}-\frac32+n-r\right)_{n=0,1,..,n-1}.$$

$$A_n = 1$$

For Kober (1940)

$$t^a K^-_{\rho,a}[\phi(t)] = K^-_{\rho+a,a}[t^a\phi(t)]$$

Therefore

$$K^-_{\lambda+\frac12-\frac{\nu}{2},\,\frac{\nu}{2}}[f(s)] = s^{\lambda+\frac12-\frac{\nu}{2}}K^-_{0,\,\frac{\nu}{2}}\left[s^{\nu/2-\frac12-\lambda}f(s)\right]$$

Now

$$\frac{d^n}{ds^n}\left\{s^{-\lambda}K^-_{\lambda+\frac12-\frac{\nu}{2},\,\frac{\nu}{2}}f(s)\right\} = \frac{d^n}{ds^n}\left[s^{-\frac{\nu}{2}+\frac12}\, K^-_{0,\,\frac{\nu}{2}}\left\{s^{\nu/2-\lambda-\frac12}f(s)\right\}\right]$$

$$= \sum_{r=0}^{n} {}^nC_r\frac{d^{n-r}}{ds^{n-r}}s^{-\nu/2+\frac12}\cdot\frac{d^r}{ds^r}\left[K^-_{0,\,\frac{\nu}{2}}\left\{s^{\nu/2-\lambda-\frac12}f(s)\right\}\right]$$

But

$$\frac{d^h}{ds^h}K^-_{0,\,\frac{\nu}{2}}\left[s^{\nu/2-\frac12-\lambda}f(s)\right]$$

$$= \frac{d^h}{ds^h}\left[\frac{1}{\Gamma\left(\frac{\nu}{2}\right)}\int_s^\infty (x-s)^{\nu/2-1}x^{-\lambda-\frac12}f(x)\,dx\right]$$

$$= \frac{(-1)^h}{\Gamma\left(\frac{\nu}{2}-h\right)}\int_s^\infty (x-s)^{\nu/2-h-1}x^{h-\nu/2}\left[x^{\nu/2-\lambda-h-\frac12}f(x)\right]dx$$

$$= (-1)^h K^-_{0,\,\frac{\nu}{2}-h}\left[s^{\nu/2-\lambda-h-\frac12}f(s)\right]$$

Therefore

$$\frac{(-1)^n s^{\lambda+n+1}}{\Gamma(\lambda+n+1)}\frac{d^n}{ds^n}\left[s^{-\lambda}K^-_{\lambda+\frac12-\frac{\nu}{2},\,\frac{\nu}{2}}\{f(s)\}\right]$$

$$= \frac{1}{\Gamma(\lambda+n+1)} \sum_{r=0}^{n-1} {}^{n}C_r \left(\frac{\nu}{2} - \tfrac{1}{2} \right) \cdots\cdots \left(\frac{\nu}{2} - \frac{3}{2} + n - r \right).$$

$$s^{\lambda + \frac{3}{2} - \frac{\nu}{2} + r} \; K^{-}_{0,\, \nu/2-r} \left[s^{\nu/2-\lambda-\frac{1}{2}-r} f(s) \right]$$

$$+ \frac{s^{\frac{1}{2}-\nu/2}}{\Gamma(\lambda+n+1)} \; K^{-}_{0,\, \nu/2-n} \left[s^{\nu/2-\lambda-\frac{1}{2}-n} f(s) \right]$$

$$= \frac{s}{\Gamma(\lambda+n+1)} \sum_{r=0}^{n} A_r \, K^{-}_{\lambda+\frac{1}{2}-\nu/2+r,\, \nu/2-r} f(s).$$

where Ar and A_n are as given above.

Hence

$$W_{n,x}\,[G(s)] = W_{n,x}\left[K^{-}_{\lambda+\frac{1}{2}-\nu/2,\, \nu/2} f(s) \right]$$

$$= \frac{\left(\frac{n}{x} \right)}{\Gamma(\lambda+n+1)} \sum_{r=0}^{n} Ar \, K^{-}_{\lambda+\frac{1}{2}-\nu/2+r,\, \nu/2-r} f\left(\frac{n}{x} \right)$$

Hence the result

Theorem 3.4

If the function $f(s)$ has the representation (1.1) with $\phi(t) \,\varepsilon\, L_p(0, \infty)$, $p \geqslant 1$, $s > 0$ and $\lambda > -\frac{1}{q}$ when $\nu < 0$ and $\lambda + \frac{1}{2} - \frac{\nu}{2} > -\frac{1}{q}$ when $\nu > 0$ then

$$\lim_{n \to \infty} \int_0^\infty \left| W_{n,t} f(s) \right| dt = \int_0^\infty \left| I^{+}_{\lambda+\frac{1}{2},\, -\nu/2} \phi(t) \right|^p dt \qquad ..(3.7)$$

Proof:—

If $f(s)$ has the representation (1.1) then

$$f(s) = \int_0^\infty K^{-}_{\lambda+\frac{1}{2},\, -\nu/2} \left| (st)^{\lambda} e^{-st} \right| \phi(t)\, dt$$

$$= \int_0^\infty (st)^{\lambda} e^{-st} \, I^{+}_{\lambda+\frac{1}{2},\, -\nu/2} [\phi(t)]\, dt$$

Since Erdèlyi (1940)

$$\int_0^\infty dx\, f(x)\, I^{+}_{\eta,\alpha} [\phi(x)] = \int_0^\infty dx\, \phi(x)\, K^{-}_{\eta,\alpha} f(x).$$

where $f(x)$ and $\phi(x)$ both belong to $L_p(0, \infty)$

Also if $\phi(t) \varepsilon L_p(0, \infty)$ then

$I^{+}_{\lambda+\frac{1}{2}, -\nu/2} [\phi(t)] \varepsilon L_p(0, \infty)$

provided $\lambda+\frac{1}{2} > -\dfrac{1}{q}$.

Therefore as in theorem 3.3 we have

$$\lim_{n \to \infty} \int_0^\infty \left| W_{n,t} [f(s)] \right|^p dt = \int_0^\infty \left| I^{+}_{\lambda+\frac{1}{2}, -\nu/2} [\phi(t)] \right|^p dt.$$

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NON STATIONARY FLOW OF A CONDUCTING FLUID IN A POROUS ANNULAR TUBE

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SUMMARY

An exact solution of modified Navier-Stokes equations governing the flow of a conducting fluid in an infinite porous annular cylinder in presence of a radial magnetic field has been investigated in this paper. In special cases it has been shown that the values of injection velocity, to some extent, have its effect on the fluid velocity and also on the magnetic field.

INTRODUCTION

The stationary and non-stationary flows of a conducting fluid in an annular tube have been investigated by various authors[2],[3],[5]. Recently Shukla[4] has also considered to non-stationary flow of a conducting fluid in a porous cylindrical annulus and an exact solution has been found. He has also investigated the effect of injection on the flow past of the porous cylinder. But in the process he has prescribed a boundary condition which needs reconsideration. As such in this paper an attempt has been made to find the exact solution of the modified Navier-Stokes equations using a more general boundary condition. It will also be shown that Shukla's[4] result comes out to be a particular case of the present results obtained here.

BASIC EQUATIONS

The fundamental equations of Hydromagnetics governing the flow are:

$$\frac{\partial v}{\partial t}+(v.\,V)\,v=-\frac{1}{\rho}\,\nabla p+\frac{\mu}{\rho}\nabla^2 v+\frac{\mu_e}{\rho}J\times H \qquad ..(1)$$

$$\text{div } v=0 \qquad ..(2)$$

$$\text{div H}=0 \qquad ..(3)$$

$$\text{curl H}=J \qquad ..(4)$$

$$\text{div E}=0 \qquad ..(5)$$

$$\text{curl E}=-\mu_e\,\frac{dH_0}{dt} \qquad ..(6)$$

$$J=\sigma[E+\mu_e\,(v\times H)] \qquad ..(7)$$

where v, E, H, J denote velocity, electric field, magnetic field and current density vector respectively and $p, \mu, \mu_e, \rho, \sigma$ denote pressure, coefficient of viscosity, magnetic permeability, density and conductivity of the fluid respectively.

From (1)—(7) we hare:

$$\frac{\partial v}{\partial t}+(v.\,\nabla)\,v=-\frac{1}{\rho}\,\nabla p+\nu\Delta^2 v+\frac{\mu_e}{\rho}\,\text{curl H}\times\text{H} \qquad ..(8)$$

$$\frac{\partial \text{H}}{\partial t}=\text{curl }(v\times\text{H})+\eta\nabla^2\text{H} \qquad ..(9)$$

where $\eta=1/(\sigma\mu_e)$ is the magnetic diffusivity of the field and ν the kinematic viscosity of the fluid.

Consider the axial flow of a conducting fluid in a porous cylindrical annulus whose transverse section is bounded by the circles $r=a$ and $r=b$ $(a<b)$ under the radial magnetic field $\text{H}_r=\text{H}_0\ (a/r)$.

The radial injection velocity $v_r=v_0\ (a/r)$ is also superimposed on the flow, v_0 the injection velocity at the inner cylinder which is moving parallel to its axis with the Velocity $(u_0/\mu_0)\ e^{\text{K}\tau}$ (u_0) is some characteristic velocity, $\tau=\text{U}_0\ t/a$ is the dimensionless time, K is dimensionless constant and μ_0 is the square root of the magnetic Reynold's number defined in (14) below.

In the present problem, we take all the physical quantities as the function of r and t only and use cylindrical polar coordinates (r, θ, z).

$$\text{Thus}\quad v=(\text{V}_r,\,0,\,\text{V}_z) \qquad ..(10)$$
$$\text{H}=(\text{H}_r,\,0,\,\text{H}_z)$$

and by (8) and (9), using (10) we have:

$$\frac{\partial}{\partial r}\left[\frac{v_r^2}{2}+\frac{p}{\rho}+\frac{\mu_e}{2\rho}\,\text{H}_z^2\right]=0 \qquad ..(11)$$

$$\frac{\partial v_z}{\partial t}+\frac{v_0 a}{r}\,\frac{\partial v_z}{\partial r}=\nu\left[\frac{\partial^2 v_z}{\partial r^2}+\frac{1}{r}\,\frac{\partial \text{V}_z}{\partial r}\right]+\frac{\mu_e\text{H}_0 a}{\rho r}.\,\frac{\partial \text{H}_z}{\partial r} \qquad ..(12)$$

$$\frac{\partial \text{H}_z}{\partial t}+\frac{v_0 a}{r}\,\frac{\partial \text{H}_z}{\partial r}=\eta\left[\frac{\partial^2 \text{H}_z}{\partial r^2}+\frac{1}{r}\,\frac{\partial \text{H}_z}{\partial r}\right]+\frac{\text{H}_0 a}{r}\,\frac{\partial v_z}{\partial r} \qquad ..(13)$$

We can find E, J and p by (4), (6) and (11) if H_z and v_z are known. Thus we have to determine v_z and H_z from (12) and (13).

Using the following transformations,

$$v_z=\frac{u_0}{\mu_0}\,v,\ \text{H}_z=\frac{\text{H}_0}{\lambda_0}\,\text{H},$$

$$r=ax,\ t=\frac{a}{u_0}\,\tau,$$

$$\text{R}=\frac{u_0 a}{\nu};\qquad \text{S}=\frac{\mu_e}{\rho}\,\frac{\text{H}_0^2}{u_0^2}$$

$$
\begin{aligned}
v_e &= \frac{v_0}{u_0} \\
\lambda_0{}^2 = \mathrm{SR} &= \frac{a\mathrm{H}_0{}^2\mu_e}{\mu\mu_0} \\
\mu_0{}^2 = \mathrm{R_e} &= \frac{u_0 a}{\eta} \\
\mathrm{M} = \lambda_0\,\mu_0 &= \sqrt{\mathrm{SRR_e}} = a\mathrm{H}_0\mu_e\,\sqrt{\sigma/\mu}
\end{aligned}
\qquad ..(14)
$$

we get from (12) and (13):

$$\frac{\partial^2 v}{\partial x^2} + \frac{1}{x}\left[(1-v_e\,\mathrm{R})\frac{\partial v}{\partial x} + \mathrm{M}\frac{\partial \mathrm{H}}{\partial x}\right] - \mathrm{R}\frac{\partial v}{\partial \tau} = 0 \qquad ..(15)$$

$$\frac{\partial^2 \mathrm{H}}{\partial x^2} + \frac{1}{x}\left[(1-v_e\,\mathrm{R_e})\frac{\partial \mathrm{H}}{\partial x} + \mathrm{M}\frac{\partial v}{\partial x}\right] - \mathrm{R_e}\frac{\partial \mathrm{H}}{\partial \tau} = 0 \qquad ..(16)$$

where x, τ are dimensionless independent parameters, R the Reynold's number, $\mathrm{R_e}$ the magnetic Reynold's number, S the magnetic pressure number, M the Hartmann's number, v_e the injection parameter and λ_0, μ_0 are dimensionless constants.

INTEGRATION OF EQUATIONS

Taking:

$$\left.\begin{aligned} v &= \mathrm{U}\, e^{\mathrm{K}\tau} \\ \mathrm{H} &= h\, e^{\mathrm{K}\tau} \end{aligned}\right\} \quad 0 < \tau < \infty \qquad ..(17)$$

We have from (15) and (16) :

$$\frac{d^2 u}{dx^2} + \frac{1}{x}\left[(1-v_e\,\mathrm{R})\frac{du}{dx} + \mathrm{M}\frac{dh}{dx}\right] - \alpha^2 u = 0 \qquad ..(18)$$

$$\frac{d^2 h}{dx^2} + \frac{1}{x}\left[(1-v_e\,\mathrm{R})\frac{dh}{dx} + \mathrm{M}\frac{du}{dx}\right] - \alpha^2 h = 0 \qquad ..(19)$$

where $\alpha^2 = \mathrm{RK} = \mathrm{R_e\,K}$.

To solve the equations (18) and (19) we assume

$$\left.\begin{aligned} u &= f + g \\ h &= f - g \end{aligned}\right\} \qquad ..(20)$$

where f and g are functions of x. Putting the values of u and h from (20) in (18) and (19) and after addition and subtraction of the resulting equations we get

$$\left.\begin{aligned} \frac{d^2 f}{dx^2} + \frac{1-2m}{x}\frac{df}{dx} - \alpha^2 f &= 0 \\ \frac{d^2 g}{dx^2} + \frac{1-2n}{x}\frac{dg}{dx} - \alpha^2 g &= 0 \end{aligned}\right\} \qquad ..(21)$$

where

$$\left.\begin{aligned} 2m &= v_c\,\mathrm{R} - \mathrm{M}. \\ 2n &= v_c\cdot\mathrm{R} + \mathrm{M}. \end{aligned}\right\} \qquad ..(22)$$

Equations in (21) are well known modified Bessel's equations whose solutions are

$$f = x^m[AI_m(ax) + BK_m(ax)]. \qquad \ldots(23)$$
$$g = x^n[CI_n(ax) + DK_n(ax)].$$

where A, B, C, D are constants and $I_m\ (ax)$, $K_m\ (ax)$ etc. are modified Bessel's functions of first and second kind. Thus (20) and (23) are the solutions of the equations (18) and (19) and using these values of f and g in (17) we get

$$v = e^{K\tau}[x^m\{AI_m(a_x) + BK_m(a_x)\} + x^n\{CI_n(a_x) + DK_n(a_x)\}].$$
$$H = e^{K\tau}[x^m\{AI_m(a_x) + BK_m(a_x)\} - x^n\{CI_n(a_x) + DK_n(a_x)\}]. \qquad \ldots(24)$$

BOUNDARY CONDITIONS

From equations (7) and (10) it can be shown by following the arguments similar to those of Agarwal[1] that

$$J_r = J_z = E_r = E_z = 0 \qquad \ldots(25)$$

and

$$J_\theta = \sigma[E_\theta + \mu_e(v_z H_r - v_r H_z)] = -\left(\frac{\partial H_z}{\partial_r}\right) \qquad \ldots(26)$$

Since the only current in the channel is J_θ it behaves like a current in a solenoid (infinite at both ends) and hence it produces an axial component of magnetic field for the region $0 \leqslant r < b$, $-\infty < z < +\infty$. If a current J_θ is considered in the solenoid, the magnetic field H_z along the axis is given by

$$H_z = 4\pi n J_\theta$$

which with the help of (14) gives,

$$H = \frac{4\pi n\lambda_o}{H_o} J_\theta \qquad \ldots(27)$$

where n is number of turn of coil in the solenoid.

Using (27) in (17) we get

$$H = h = \frac{4\pi n\lambda_b}{H_o} \cdot \frac{J_\theta}{e^{K\tau}}$$

or

$$h = \frac{PJ_\theta}{e^{K\tau}}. \qquad \ldots(28)$$

Where

$$P = \frac{4\pi n\lambda_o}{H_o}.$$

Now if it is assumed that at $x=1$ or $r=a$

$$J_\theta = J_a.$$

The boundary condition at $r=a$ is

$$u=1,\ h=\frac{\mathrm{PJ}_a}{{}_e\mathrm{K}_\tau}. \qquad ..(29)$$

But as regards outer wall, if it is non-conducting (permeability same as that of the fluid), $h=0$ for $x=b/a$ and if there is no applied electric field, then $\mathrm{E}_\theta=0$ for $r=b$ and since $\mathrm{V_z}=\mathrm{H_z}=0$ there, $\frac{\partial \mathrm{H_z}}{\partial_r}=0$ and $\frac{dh}{dx}=0$ for $x=b/a$ from equations (26). As such

$$u=0,\ h=0 \text{ when } x=b/a \text{ or } \infty. \qquad ..(30)$$

Using the boundary conditions given by (29) and (30) in (24) we obtain the values of the constants A, B, C, D as follows:

$$\mathrm{A}=\mathrm{C}=0$$

$$\mathrm{B}=\frac{1+\mathrm{PJ_a}}{2\mathrm{K_n}(\alpha)},\ \mathrm{D}=\frac{1-\mathrm{PJ_a}}{2\mathrm{K_n}(\alpha)} \qquad ..(31)$$

Using (31) in (24) we get

$$v=\frac{{}_e\mathrm{K}_\tau}{2}\left[\left\{x^{\mathrm{m}}\frac{\mathrm{K_m}(\alpha_\mathrm{x})}{\mathrm{K_m}(\alpha)}+x^{\mathrm{n}}\frac{\mathrm{K_n}(\alpha_\mathrm{x})}{\mathrm{K_n}(\alpha)}\right\}+\left\{x^{\mathrm{m}}\mathrm{PJ_a}\frac{\mathrm{K_m}(\alpha_\mathrm{x})}{\mathrm{K_m}(\alpha)}-x^{\mathrm{n}}\mathrm{PJ_a}\frac{\mathrm{K_n}(\alpha_\mathrm{x})}{\mathrm{K_n}(\alpha)}\right\}\right]$$

$$\mathrm{H}=\frac{{}_e\mathrm{K}_\tau}{2}\left[\left\{x^{\mathrm{m}}\frac{\mathrm{K_m}(\alpha_\mathrm{x})}{\mathrm{K_m}(\alpha)}-x^{\mathrm{n}}\frac{\mathrm{K_n}(\alpha_\mathrm{x})}{\mathrm{K_n}(\alpha)}\right\}+\left\{x^{\mathrm{m}}\mathrm{PJ_a}\frac{\mathrm{K_m}\ \alpha_\mathrm{x})}{\mathrm{K_m}(\alpha)}+x^{\mathrm{n}}\mathrm{PJ_a}\frac{\mathrm{K_n}(\alpha_\mathrm{x})}{\mathrm{K_n}(\alpha)}\right\}\right] \qquad ..(32)$$

or

$$v=\frac{{}_e\mathrm{K}_\tau}{2}\,[\mathrm{A}'+\mathrm{PJ_a}\mathrm{B}'].$$

$$\mathrm{H}=\frac{{}_e\mathrm{K}_\tau}{2}\,[\mathrm{B}'+\mathrm{PJ_a}\mathrm{A}']. \qquad ..(33)$$

where

$$\mathrm{A}'=x^{\mathrm{m}}\frac{\mathrm{K_m}(\alpha_\mathrm{x})}{\mathrm{K_m}(\alpha)}+x^{\mathrm{n}}\frac{\mathrm{K_n}(\alpha_\mathrm{x})}{\mathrm{K_n}(\alpha)}$$

$$\mathrm{B}'=x^{\mathrm{m}}\frac{\mathrm{K_m}(\alpha_\mathrm{x})}{\mathrm{K_m}(\alpha)}-x^{\mathrm{n}}\frac{\mathrm{K_m}(\alpha_\mathrm{x})}{\mathrm{K_n}(\alpha)} \qquad ..(34)$$

PARTICULAR CASES

Case I. $\mathrm{J}_\theta=0$. If it is assumed that the current due to the solenoidal nature is ineffective we get

$$\mathrm{J}_\theta=0 \qquad ..(35)$$

Using (35) in (33) we get

$$v=\frac{{}_e\mathrm{K}_\tau}{2}\,\mathrm{A}',\ \mathrm{H}=\frac{{}_e\mathrm{K}_\tau}{2}\,\mathrm{B}' \qquad ..(36)$$

which are the same results as obtained by Shukla in (4).

Case II. $PJ_a=1$. When PJ_a is taken to be one, which is finite possible in view of the various constants involved in PJ_a, we find that v and H both are equal and they are given as

$$v=H=e^{K\tau}x^m\frac{K_m(\alpha_x)}{K_m(\alpha)}$$

For further study of the results it is useful to draw a chart of the values of A′, B′, and $x^m\frac{K_m(\alpha_x)}{K_m(\alpha)}$. For more special cases,

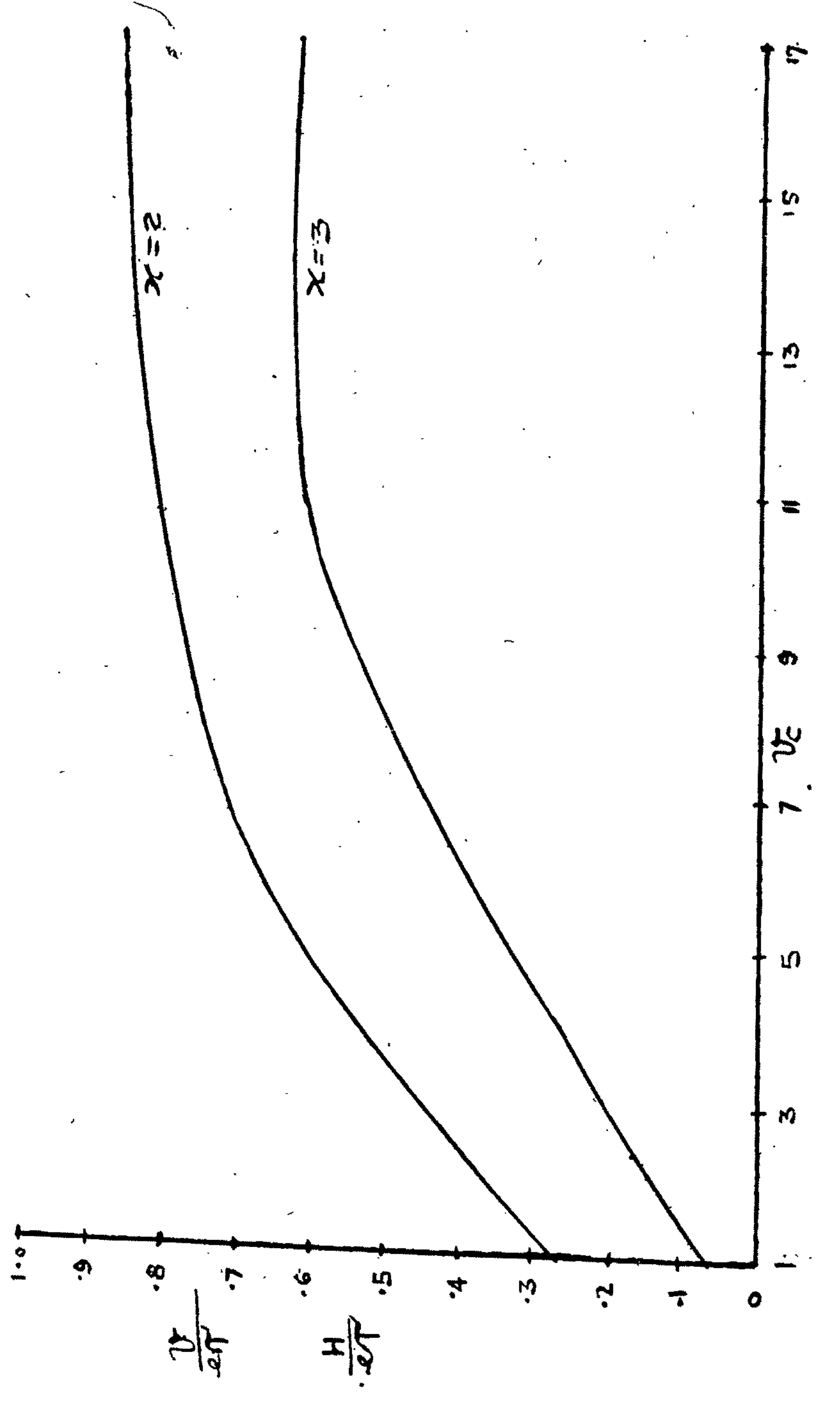
put $R=R_e=S=\alpha=1$. Thus using (22) and last of (14) we have

$$m=\frac{v_c-1}{2},\ n=\frac{v_c+1}{2}$$

x	v_c	$x^m\frac{K_m(\alpha_x)}{K_m(\alpha)}$	A′	B′
3	1	0·08	0·28	−0·12
	3	0·2	0·542	−0·142
	5	0·342	0·802	−0·12
	7	0·46	1·02	−0·10
	9	0·560	1·192	−0·07
	11	0·6318	1·288	−0·02
	13	0·6561	1·312	0
	15	0·6561	1·312	0
	17	0·6561		
2	1	0·27	0·74	−0·20
	3	0·47	1·10	−0·16
	5	0·63	1·36	−0·10
	7	0·73	1·52	−0·06
	9	0·79	1·61	−0·03
	11	0·82	1·684	−0·04
	13	0·864	1·747	−0·02
	15	0·883	1·779	−0·013
	17	0·896		

From the table above it is interesting to note the following points:

1. Case II, that is, when PJ_a is one, it is found that the velocity v and the magnetic field H both increase with the increase in values of $v_c>1$ at a given instant. But as v_c increases, the rate of increase in v and H diminishes and ultimately increase of v_c has no marked effect on v and H. This observation is most evident in the graph drawn in Figure 1.



EFFECT OF THE INJECTION ON THE INDUCED MAGNETIC FIELD AND THE VELOCITY.

2. The value of A′ is positive and that of B′ is negative. Whereas A′ increases with v_c, B′ decreases in magnitude tending to zero. Therefore even if PJ_θ is not one but any other value, it is found that v and H will still increase with v_c though v and H have different values. But in this regard the following reservations are also to be noted :

(*i*) If PJ_a is small fraction tending to zero we get positive values for v and negative values for H similar to results obtained in case I.

(*ii*) If PJ_a is very large we may get negative values even for v for small values of v_c while H remains positive.

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I wish to express my sincere gratitude and cordial thanks to Dr. B.B. Lal, Professor of Mathematics, K. N. Govt. College, Gyanpur (Varanasi) for his help and guidance in the preparation of this paper.

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INITIAL MOTION DUE TO TWO EQUAL RECTILINEAR VORTICES OUTSIDE TWO CYLINDERS WITH CASSINI'S OVALS AS SECTION

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Introduction

Agarwal [1] in one of his research papers has considered the initial motion due to two equal rectilinear vortices outside two cylinders with Cassini's ovals as sections. The vortices have been taken parallel to the generators of the cylinders which have same circulation round each of them, the circulation being equal to the strength of each vortex but opposite to their sense of rotation. An infinite mass of inviscid liquid surrounds them and is at rest at infinity. He obtained the stream lines by taking $\psi = \frac{\pi}{4}$ and has shown that the stream lines are Cassini's ovals. In this way he proved that the initial motion due to two parallel rectilinear vortices at $(0, a)$ and $(0, -a)$ in the presence of two oval cylinders with circulation K round each of them will be the same as due to the four parallel rectilinear vortices at $(a, 0)$, $(0, a)$, $(-a, 0)$ and $(0, -a)$ with proper sense.

Here we propose to show that whatever be the value of the constant, positive or negative, $\psi = C$ (constant), are always Cassini's ovals. The only restriction that we have to impose is that C must lie between -1 and $+1$. Thus we get the solution of the problem of two rectilinear vortices being situated outside two Cassini's ovals in a number of cases in which the Cassini's ovals differ in size as well as in respect of distances between the foci while the distance between the vortices remains unchanged.

Solution

Taking the axis of z parallel to the vortices and let the vortices be situated at P $(a, 0)$ ↺, Q $(0, a)$ ↺, R $(-a, 0)$ ↻ and S $(0, -a)$ ↻ in the xy plane and let each be of strength K the sense of rotation is as shown in the diagram.

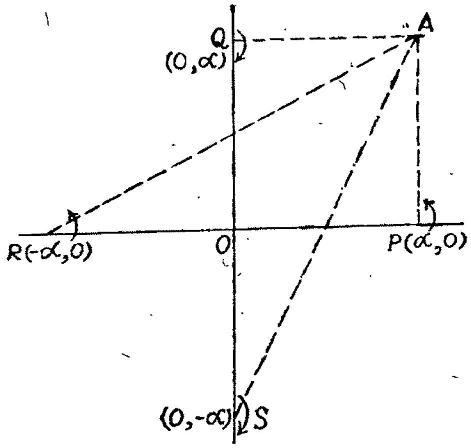

Fig. 1

The stream function is

$$\psi=\frac{K}{2\pi}\Big[\log PA-\log QA+\log RA-\log SA\Big]$$

$$=\frac{K}{4\pi}\log\frac{(\alpha^2+r^2-2\alpha r\cos\theta)\,(\alpha^2+r^2+2\alpha r\cos\theta)}{(\alpha^2+r^2-2\alpha r\sin\theta)\,(\alpha^2+r^2+2\alpha r\sin\theta)} \qquad ..(A_1)$$

Stream lines are given by,

$$\frac{(\alpha^2+r^2-2\alpha r\cos\theta)\,(\alpha^2+r^2+2\alpha r\cos\theta)}{(\alpha^2+r^2-2\alpha r\sin\theta)\,(\alpha^2+r^2+2\alpha r\sin\theta)}=\text{const.}=n\ (\text{say}).$$

Thus : $\dfrac{(\alpha^2+r^2)^2-4\,\alpha^2r^2\cos^2\theta}{(\alpha^2+r^2)^2-4\,\alpha^2r^2\sin^2\theta}=n$

or $(1-n)\,(\alpha^4+2\,\alpha^2r^2+r^4)-4\,\alpha^2r^2\,(\cos^2\theta-n\sin^2\theta)=0$

or $(1-n)r^4-2\,\alpha^2r^2\,(2\cos^2\theta-2n\sin^2\theta-1+n)+(1-n)\alpha^4=0$

or $(1-n)r^4-2\,\alpha^2r^2\,(2\cos^2\theta-1)(1+n)+(1-n)\alpha^4=0.$ ..(1)

i. e. $r^4-2\,\alpha^2\,\dfrac{1+n}{1-n}\,r^2\cos2\theta+\alpha^4=0$ ..(2)

Putting $\dfrac{1+n}{1-n}\alpha^2=a^2$, so that $\alpha^4=a^4-\dfrac{4na^4}{(1+n)^2}$

(2) gives,

$$r^4-2a^2r^2\cos2\theta+a^4-\frac{4n\,a^4}{(1+n)^2}=0 \qquad ..(3)$$

From Ganguli [2] we know that

$$r^4-2\,a^2r^2\cos2\theta+a^4-c^4=0 \qquad ..(4)$$

represents two ovals if $a^2>c^2$ and the coordinates of the foci are $(-a, 0), (a, 0)$. Comparing equations (3) and (4) we see that the condition for two ovals is satisfied if $a^2>\left(\dfrac{2n^{\frac{1}{2}}}{1+n}\right)a^2$ and then the foci of the Cassini's ovals are,

$$\left(-\alpha\frac{\sqrt{1+n}}{1-n},0\right)\text{ and }\left(+\alpha\frac{\sqrt{1+n}}{1-n},\,0\right).$$

Now the foci will be real if

$\frac{1+n}{1-n}$ is $+ve$ i. e. $-1<n<1$.

Thus the vortices at $(a, 0)$ ↺ and $(-a, 0)$ ↺ may be regarded as images of the two vortices at $(0, a)$ ↻ and $(0, -a)$ ↻ with respect to the ovals. But the two vortices inside the ovals would produce a circulation K round each of the cylinders, which is a part of our data.

Hence the initial motion due to two parallel rectilinear vortices at $(0, a)$ ↻ and $(0, -a)$ ↻ in the presence of two ovals cylinders with circulation K round each of them will be the same as due to the four parallel rectilinear vortices at $(a, 0)$ ↺, $(0, a)$ ↻, $(-a, 0)$ ↺ and $(0, -a)$ ↻. It will be noted that this will be true only in the case of initial motion as the vortices will be moving and changing their positions relatively to the fixed cylinder, so that their images will also change. The above analysis will fail to give the images in the changed position. Hence for initial motion the stream function ψ is given by

$$\psi=\frac{K}{4\pi}\log\frac{(a^2+r^2-2ar\cos\theta)\,(a^2+r^2+2ar\cos\theta)}{(a^2+r^2-2ar\sin\theta)\,(a^2+r^2+2ar\sin\theta)}.$$

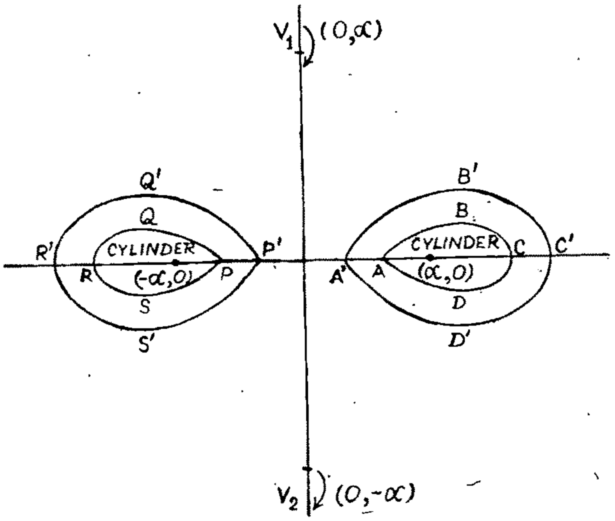

Fig. 2

In the above figure if A, B, C, D and P, Q, R, S are the sections of the cylinders and vortices are situated at V_1 and V_2, this will be problem No. 1. Again, if A′B′C′D′ and P′Q′R′S′ are the sections of the cylinders and V_1 and

V_2 are the vortices, this will be problem No. 2. We have shown that the solution of both these problems is the same. In fact there will be infinitely many problems of this nature, the solution of which is result (A_1).

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Abstract of Theses

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BLOSSOM BUD DIFFERENTIATION, DEVELOPMENT OF MALE AND FEMALE GAMETOPHYTES AND FRUIT-SET IN LOQUAT (*ERIOBOTRYA JAPONICA* LINDL.)[1]

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SUMMARY

The knowledge of the fruit bud differentiation has been acclaimed by the breeders in their hybridization programmes and by the practical horticulturists for their fruit industry all over the world. It enables them to conduct investigations as to the effect of special treatments upon blossom bud differentiation and organogenesis. Further more, if the time of blossom bud primordia formation could be known, it will enable the orchardists to take initiative at the right time for cultural treatments. Similarly, the male and female parents, the pollen grain and the female gamete constitute the main items of the plant breeder which play a vital role in the evolution of new varieties. These male and female gametophytes are composed of tiny cells, in which all the potentialities and characters of the plants are present and their study along with fruit bud differentiation is of great importance. With this objective in view, the present studies on the various aspects of its growth, fruit bud differentiation, development of male and female gametophytes and bearing habits to fill up the lacunae in our knowledge about Loquat, were undertaken at the Department of Horticulture, Government Agricultural College, Kanpur during 1960-61 to 1963-64. The results are summarized below:—

1. (a) Two distinct vegetative flushes were observed in Loquat, first in March and April and the second one in July and August.

(b) The emergence of vegetative shoots completely ceased in the period from November to January.

(c) The vegetative shoots took from two and a half to twelve months to mature themself to differentiate into flower buds.

(d) The time required for flower bud development in both the varieties of loquat was found from 29 to 33 days. The flowers remained open for 2 to 3 days.

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[1] Abstract of the thesis submitted to and approved by the Agra University, Agra for the degree of Doctor of Philosophy in Horticulture.

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(e) There were two periods of blossom bud differentiation. The blossom bud differentiation began from first week of July and continued upto middle of October in case of first flush, however, in second flush the differentiation continued upto middle of December. The percentage of blossom bud formation increased with the fall of the temperature from July to December. It was recorded maximum in second flush, in the month of October and November.

(f) Observations on the mode and time of emergence of shoots in respect of the fruit bud differentiation, showed that the fruit buds were formed on old and new shoots irrespective of the time of their emergence in both the varieties. It was clearly shown that the age of shoots did not govern fruit bud formation in case of Loquat.

(g) Studies on the extension of growth of loquat shoots have shown that in both the varieties shoots generally extended every year and young shoots did not differentiate fruit buds whether the cessation of growth was earlier or later in the season. Similarly, unextended shoots were equally capable for forming fruit buds.

(h) Observations on the shoot size in respect of the fruit bud differentiation showed that there appeared to be no relationship between the length, girth and number of leaves per shoot and fruit bud differentiation.

(i) Observations of the longitudinal section of the buds showed that vegetative and fruit buds in the initial stages were identical in their structure. The first sign of fruit bud differentiation was recorded by the slight broadening elongation of the bud along with the presence of many scales. The process of fruit bud differentiation was found to be a continuous one and it took place in the growing shoots throughout the growing season. Time required for the fruit bud differentiation from its initiation to the final development was found to vary depending upon the condition of the shoot growth and its maturity.

(j) Buds were found more developed afterwards due to the formation of primordia of secondary branches which appeared laterally. The formation of lobes in the secondary branches was the sign of either of further branching or of the formation of flower primordia. Primary, secondary or tertiary, branches as well as the floral primordia differentiated in the axils of young bracts. At the stage of bud break flower primordia started organogeny of the flower and loosening of the scales. The elongation of the floral axis took place at the stage of bud burst.

2. (a) The male gametophyte was found to differentiate and develop to maturity in the normal way.

(b) The female gametophyte showed that the embryo sac was typical of a monosporic 4-nucleate of Oenothera type.

(c) The endorsperm development was found normal by regular and irregular division of its nuclei.

(d) The mature embryo was straight and was enclosed within a single layer of endorsperm cells which in turn was covered by a thin layer of nucellus. An air cavity used to develop in the centre of nucellus. The mature normal seeds more or less were oval, deep brown in colour and had a smooth surface. The seed coat was found to develop from the outer epidermis of the outer integument and the inner integument excepting its inner epidermis and one or two adjoining layers of cells.

3. The maximum number of panicles (86, 110 and 92, 106) was observed in November 1960 and 1961 in Pale yellow, Golden yellow varieties respectively, while minimum number of panicles was found in the month of September in both the years.

The mixed buds appeared in the month of July. The vegetative shoots devloped at their basal portion. Fruit bud differentiation took place in these shoots in the next season.

4. 1 to 7 vegetative shoots were recorded in mixed panicles. It was found that the panicles which appeared with large number of vegetative shoots, showed considerable abortion of panicles and the vegetative shoots continued their growth.

5. The peak period of flowering under local conditions was from November to first fortnight of January though it began in September and continued upto the third week of January.

6. Time required for completion of anthesis was found to be 10 and 12 hours in Golden yellow and Pale yellow varieties respectively. The rise in temperature increased the intensity of anthesis. The maximum anthesis occurred between 10 a.m. and 2 p.m. in both the varieties. The flower buds borne on apical portion of branches of panicles opened earlier than those of lateral clusters.

7. The dehiscence of anthers, which took place in longitudinal fashion, was maximum between 10 a.m. to 2. p.m. in Golden yellow variety though it started from 8 a.m. and continued throughout the whole day, however, this process was completed in more than a day in Pale yellow variety. There was slight relationship between dehiscence and temperature, as the process of dehiscence was hastened with the rise in temperature in case of Golden yellow variety. No varietal differences were observed in the patterns of anthesis and dehiscence.

8. The pollen grains of both the varieties of loquat were similar in shape and symmetry with a very little difference in their size. The pollen grains of both the varieties were binucleate at the time of shedding. They were isopolar, radiosymmetric, angulaperturate and 3-colporate. The shape was prolate, spherical but the sterile pollen grains were small and had no definite shape. Fertile pollen grains were observed to be on an average 24·3 μ in Golden yellow and 25·2 μ in Pale yellow variety in size.

9. The maximum percentage of pollen sterility was observed in the first flush (July and August) and last bloom (January), while it was the lowest (6·95) in Pale yellow and (13·66) Golden yellow in the middle of flowering season.

10. The "giant sized" pollen grains were also observed with 4 germ-pores instead of 3, suggesting the formation of restitution nuclei.

11. In the trials of germination of pollen grains in artificial media, maximum germination of 74·91, 83·76 and 85·92 per cent was found in 1·5, 2·25 and 5·5 per cent sucrose solution at 30·5°C respectively. The maximum growth of pollen tubes occurred in 4 hours of incubation of the cultures.

12. In sucrose agar medium, 0·5 per cent agar gave the best pollen germination and pollen tube growth.

13. Among the three plant regulators used with optimum sucrose solution, GA accelerated the pollen germination and pollen tube elongation while IAA and IBA proved ineffective for pollen germination.

14. The percentage of stigmas which received the pollen in open pollinated pistils in peak period of flowering was low. The pistils of early and late blooms also exhibited the lowest percentage of pollinated stigmas.

15. The results of pollen storage tests indicated that the pollen grains remained viable for about 4 months in desiccators and for 50 days in the petridishes at room temperature. The maximum viability (78·36 per cent) was found in pollen grains stored in 25 per cent relative humidity at 0°C.

16. The biological reactivity of the stored pollen of Pale yellow variety after storage for one year in proper medium was tested by pollinating stigmas and recording fruit set and it was found that pollen grains did not lose much of their viability in storage and remained capable of fertilization.

The stigma attained receptivity 8 hours prior to anthesis and remained receptive for 12 hours after opening of the flowers. The maximum percentage of receptivity (92·5) was recorded at anthesis, followed by 80·0 per cent after 4 hours of anthesis.

In pale yellow variety of loquat 59·15 and 25·91 were the maximum and minimum percentages of fruit set, recorded in natural cross pollination and hand pollination respectively. Insects were found to play an important role in the process of pollination.

17. There was total self-incompatibility in Golden yellow variety. The Pale yellow variety was partially self-imcompatible and it gave 27·4 per cent fruit set.

18. (a) Aqueous solutions of 5, 10, 20, 30, 40, 50 and 75 ppm of 2, 4, 5-T and GA were separately sprayed on loquat flowers. All the concentrations of 2,4,5-T and GA except 75 ppm gave higher percentage of fruit setting over control.

(b) Considerable increase in fruit size and weight over control was found in all the concentrations of 2,4,5-T and GA. Weight of pulp per fruit was increased with increase in concentrations of both the plant growth regulators. The maximum weight of pulp per fruit in Golden yellow variety was recorded (15·95 and 15·05 gm.) in 50 and 40 ppm treatments of 2,4,5-T and GA, respectively.

(c) Chemical analysis of fresh fruits under different treatments of 2,4,5-T and GA showed that the total soluble solids increased and total acidity decreased with the increase in concentrations of GA and 2,4,5-**T**. An increase of Ascorbic acid over control was recorded with the increase in concentrations of both the plant growth regulators. Similar results in corresponding treatments were also observed in Pale yellow variety.

(d) Fruit drop decreased progressively with the increase in concentrations of GA and 2,4,5-T. Minimum fruit drop was recorded in the maximum concentration of 75 ppm of the plant growth regulators used in both the varieties in the year 1960-61 and 1961-62.

19. (a) Studies of seasonal variation in ascorbic acid content in loquat fruits, showed that in the years 1960 and 1961, there was an increase in the amount of ascorbic acid in fruits from young stage to maturity. The maximum amount of ascorbic acid (17·081 and 17·100 mg. per 100 gm. of pulp) was found in December, 1960 in Golden yellow and Pale yellow varieties respectively, however, there was a slight variation in its content in February, 1961 in fully matured fruits. In this case maximum amount of ascorbic acid recorded was 17·206 and 17·185 mg. per 100 gm. of pulp in the year 1961 in Pale yellow and Golden yellow varieties respectively.

(b) The maximum ascorbic acid content was 17·795 and 17·790 mg. per 100 gm. of pulp in fully matured fruits in Pale yellow in 1961 and in Golden yellow variety in 1960 respectively, followed by half ripe, ripe and over ripe fruits.

20. (a) Aqueous solutions of GA, 100, 150, 200, 250, 500, 750 and 1000 ppm when sprayed on emasculated flowers, induced parthenocarpic fruit set from 31·76 to 62·85 per cent and 33·51 to 64·00 per cent in Golden yellow and Pale yellow varieties respectively.

(b) The parthenocarpic fruits were smaller in size than pollinated ones, but they were richer in total soluble solids and acid contents.

(c) Total amount of acids in fruits decreased with the increase in GA concentrations, however, the acids and total soluble solids were higher than those under control.

21. Ringing and scoring enhanced shoot growth, flowering and fruit setting. 82 and 85 per cent shoots flowered in Pale Yellow and Golden Yellow varieties by ringing, and 70 and 92 per cent shoots flowered by scoring treatments. Ringing also induced fruit drop, increased fruit size and yield per panicle.

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STUDIES ON THE INDIAN DERMAPTERA[1]

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The present thesis deals mainly with the systematics of Indian Dermaptera. The study of Indian Dermaptera is quite in its infancy. Eighty-eight species were known from India (including Nepal, Sikkim and Bhutan and excluding Burma and Ceylon) as late as 1910 since the publication of Burr's 'Fauna of British India'. Since that date certain groups have been revised and only ninty-six new forms added to the dermapteren fauna of India. Therefore, the present work aims at putting the dermapteren fauna under recent taxonomic work.

The thesis is divided into four chapters including the chapter of Summary. Chapter one, the Introductory section, gives the brief review of the previous work on Dermaptera, especially from India. This is followed by the outline of more external characters employed in the taxonomy of this group. The male genitalia has been considered the most stable character in speciation than the other external characters like head, pronotum, tegmina, wings, legs, abdomen, opisthomeres, forceps and penultimate sternite and changes in these characters will not be taken in establishing new species unless there are differences in the characters of male genitalia. In the biological portion a new apparatus, consisting of an ordinary glass chimney (with half of its basal portion black) placed on petridish (containing at the bottom a sponge piece covered with filter paper, sterilised soil and again filter paper) and a wire gauze covering the upper portion of the chimney, is employed for rearing these insects in the laboratory. The zoogeography of these insects shows a high degree of endemism.

The second chapter, bulk of the thesis, consists of the section on systematics. The classification is based on the well known works of Burr, Hincks, Brues, Melander and Carpenter and other recent authorities like Popham. All together fifty-five species are dealt with, out of these, *Cranopygia bhallaie*, *Diplatys simlaensis*, *Diplatys glenis*, *Diplatys poonaensis*, *Diplatys jogiensis*, *Diplatys* sp. ?, *Thekalabis* (new genus), *Thekalabis genitalis*, *Epilandex kodaikanalensis*, *Labia serrata*, *Chaetospania* sp. ?, *Spongiphora* sp. ?, *Forcipula quadrispinosa minor* subsp. nov., *Chelisochella* sp. ?,

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[1] Summary of the thesis on which Ph.D. has been awarded by the Agra University in 1967.

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Proreus ramamurthii, *Proreus* sp.?, *Anechura virgae*, *Forficula cherapujiae*, *Forficula baijali*, *Forficula indie*, *Forficula genitalia* and *Kosmetor josephi* are new to science. Several species, inadequately described by earlier workers, are fully described and rightly placed. Notes on distribution and field ecology are also added in many cases. Keys to genera and species are appended.

The third chapter of the thesis deals with the comprehensive taxonomic catalogue of Indian Dermaptera with complete and up-to-date reference and distribution etc. This catalogue is a first attempt of bringing together one-hundred and eighty-four species of fifty-four genera so far known from India and it might be of great help for the future workers.

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STUDIES ON THE SO-CALLED NON-SPECIFIC *BRUCELLA* AGGLUTINATION REACTIONS IN BOVINES AND THE USE OF A SOLUBLE ANTIGEN FROM *BR. ABORTUS**

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ABSTRACT

The present studies were undertaken to unravel the obscure status of the so-called non-specific *Brucella* agglutinating reactions and to elucidate the various implications of conducting different standard and supplemental or differential serological tests on sera samples of cattle and buffaloes. Six herds have been included in the present investigation which are maintained on the government organized livestock farms where routine testing and segregation of serologically positive animals is followed to control brucellosis. The herds under study were selected on the basis of their relative status of infection.

The standard tube agglutination test (STT) and the heat inactivation test (HIT) were conducted on 3335 cattle sera and 2726 buffalo sera samples supported with the standard plate agglutination test (SPT) and other supplemental or differential serological tests viz. acidified plate agglutination test (APT), Rivanol precipitation-plate test (RPT), mercaptoethanol inactivation test (MET) and the use of paper chromatography.

It has been shown that in herds where regular testing and segregation policy is strictly adhered to, the HIT can not only prove to be the most efficacious adjunct to the STT in elimination of low titre, STT suspect and even rare STT 1:40 non-specific reactions but can also be relied upon in detecting the brucella positive cases earlier. The results of the comparative study of the standard and the supplemental serological tests conducted on sera samples of these herds also revealed that while the HIT, APT, MET and the RPT were considered reliable in elimination of low titre and non-specific *Brucella* agglutination reactions, the use of the SPT and the paper chromatography were of limited value.

It has further been demonstrated that in a herd where routine "testing and segregation" policy is followed but the possible source of infection is constantly present at a distance, the HIT plays an effective role in detecting the perpe-

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* This is an abstract of the thesis submitted to the Agra University in fulfilment of the requirements for the degree of Doctor of Philosophy.

tual chain of *Brucella* infected cases earlier including the subclinical pregnant animals which otherwise would have been delayed or missed by the STT alone.

A significant conclusion derived from the studies conducted on the herd where both brucella reactor and negative animals are kept almost together is the fact that not only the standard serological tests fail to detect considerably a large number of the infected cases but the usefulness of even the HIT is jeopardised under the circumstances. However, the HIT detected about 9% more infected animals than the STT. The combination of the SPT and the APT with the STT and the HIT would not be of help in ascertaining the non-specific nature of the Brucella agglutination reactions in such a herd.

It has been shown that while some of the non-specific and low titre agglutination reactions of cattle and buffalo sera samples from herd where policy of "Test and segregation" is strictly followed, were inactivated at 56°C, some required heating of the diluted serum at 60°C for half an hour for inactivation. All such cattle and buffalo sera were, however, inactivated at 65°C in 15 minutes. From the direct linear relationship which exists between the logarithm of the reciprocal of the titre and the time of heat treatment, it has been concluded that the inactivation of low titre and non-specific agglutinins both in cattle and buffalo serum is a first order reaction. In view of the shorter half life of buffalo agglutinins more work has been suggested to find out the exact optimum temperature for conducting the HIT on buffalo sera.

The first and second trials of strain 19 vaccination revealed that thermolabile agglutinins (STT) appeared first which could be detected by the SPT and by paper chromatography as non-specific agglutinins, followed by the appearance of the thermostable (HIT) and mercaptoethanol resistant agglutinins (MET) which were detected by the APT and the paper chromatography as specific *Brucella* agglutinins. The three types of agglutinin titres (STT, HIT and MET) receded in the reverse order over a period of time. The data on the studies of the third trial of vaccination showed that the HA was the most sensitive test in detecting the early *Brucella* agglutinins followed in order by the STT and the SPT. The HIT, APT and the RPT became positive in the same order, after the appearance of thermostable agglutinins.

A heat stable water soluble antigenic fraction (HSWS) isolated from *Br. abortus* 99 was found to be Molisch positive and having ultraviolet absorption maxima between 250-260 μ. Immunological reactivity of the fraction HSWS was demonstrated by the production of agglutinins and precipitins in the sera of rabbit, guinea pig and the bovines and its serological activity was shown in gel precipitin reaction against the *Brucella* species antisera and sera from naturally infected bovines. The specificity of the indirect haemagglutination test (HA) was shown by its inhibition with the free fraction HSWS. An indirect haemolytic test (HL) for detecting *Brucella* antibodies was also studied and the sensitivity of both the HA and the HL has been found to be superior to the STT in detecting smaller quantities of the antibody. Based on the patterns of haemagglutination one more criterian for distinguishing specific and non-specific *Brucella* agglutinins has been described.

The use of the gel precipitin reaction with the antigenic fraction HSWS has been developed as an additional method for the differentiation of specific and non-specific *Brucella* agglutination reactions encountered in cattle and buffalo sera samples.

The various implications of the role of the standard and the supplemental serological tests vis a vis relative status of *Brucella* infection of herds under the field conditions of the country have been brought out and scope for further characterization of nonspecific reactions in the light of the present findings has been discussed. The necessity of reorienting the brucellosis control policy of "testing and segregation" under the prevailing Indian conditions has also been emphasized.

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SOME PROBLEMS OF ASTROPHYSICS (INTERNAL CONSTITUTION OF STARS) SPECIAL STUDY OF THE LANE-EMDEN EQUATION Etc.*

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SUMMARY

The present thesis consists of two parts : (1) the theory of polytropes; and (2) the minimal problems of stars. The first part of the thesis consists of three chapters : II, III, and IV; and the second part has been dealt with in chapter V. The chapter I gives a survey of the problem dealt with in the thesis.

The structure of a star depends on multitude of variables; and an approach toward a detailed theory is made only by introducing assumptions and approximations of various kinds with a view toward discrimination between relevant and less relevant aspects of the physical situation. It is therefore necessary to make one assumption at a time and see how far can we investigate before we need to introduce another. In the present thesis author has confined himself to the stars which are in a steady state of gravitational equilibrium and in which density does not increase outward. Below is the summary of the first part of the thesis:

It is well known that solutions of the Lane-Emden equation of index n

$$\frac{1}{\xi^2}\frac{d}{d\xi}\left(\xi^2\frac{d\theta}{d\xi}\right)=-\theta^n, \qquad ..(1)$$

which satisfy the boundary conditions

$$\theta=1;\ \frac{d\theta}{d\xi}=0 \text{ at } \xi=0, \qquad ..(2)$$

govern complete polytropes; physical variables in the polytropes are related by

$$\rho=\lambda\theta^n;\ P=k\rho^{1+\frac{1}{n}}=k\lambda^{1+\frac{1}{n}}\theta^{n+1} \qquad ..(3)$$

It has generally been believed that in a polytrope, the pressure-density relation in (3) is relevant for a particular value of n, at every point in the configuration. This belief led Hopf[5], Fowler[6] and Chandrashekhar[1] to study the behaviour of solutions of the Lane-Emden equation in the immediate neighbourhood of the origin for $n<3$, $n=3$, and $n>3$ respectively. Author has shown that at the origin, arrangement of solution-curves do not change as we change the index of the configuration. If we consider the structure of the polytropes in terms of r and P, then solutions of an equation equivalent to the Lane-Emden equation for n tending to minus one will govern the origin; and if we consider the structure in terms of r and ρ then solutions for n tending to zero will govern the origin whatever be the index of the configuration. The immediate neighbourhood of the origin is an interfacial region in which two sets of equations one governing the origin and the other governing the rest of the parts of the configuration are relevant simultaneously. The point of interface that is the extent to which the solutions governing the origin are relevant is determinable. Known solutions in the immediate neighbourhood of the origin in $(\xi;\ \theta)$—plane are relevant, to the immediate neighbourhood of the interfacial region in $(r;\ \mathrm{P})$—variables.

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We have seen above that for the study of the structure of a polytrope, the study of an equation equivalent to the Lane-Emden equation for n tending to zero and minus one is necessary to understand the arrangement of solutions at the origin; and for the study of the structure of different polytropes, study of solutions for different values of n is necessary. We are thus led to the study of solutions of the Lane-Emden equation for different values of n.

It has been believed that the Lane-Emden equation is solvable for $n=0$, 1, and 5. Further, for $n=5$ we know only E-class of solutions. Author has shown that the Lane-Emden equation for n tending to zero and minus one, in terms of ξ and θ are irrelevant; and the known solution for $n=0$ has neither any mathematical nor physical validity[9]. For n tending to zero and -1 the solutions are

$$v=2\left[(2-u)+2c\,(u-3)^{\frac{2}{3}}u^{\frac{1}{3}}\right]^{-1}, \qquad ..(4)$$

and

$$v=c'u \qquad ..(5)$$

respectively where u and v are given by

$$u=-4\pi\,\mathrm{GK}^{-\frac{2n}{n+1}}\,\frac{r\mathrm{P}^{\frac{2n}{n+1}}}{\mathrm{P}'};\ v=-\frac{r\mathrm{P}'}{\mathrm{P}}, \qquad ..(6)$$

and c' is a constant of integration. There is however no possibility of getting solutions for n tending to zero and -1 if we start with r and ρ variables. Physical and mathematical relevancy of the above solutions has been discussed in detail. Thus it has been shown that the natural variables r and P are the most suitable to the study of structure of polytropic configurations.

For $n=5$, after a few transformations and integrations, Emden's equation takes the form

$$\frac{dz}{dt}=\pm\left[2\mathrm{D}+\frac{z^2}{4}-\frac{2^6}{12}\right]^{\frac{1}{2}}, \qquad ..(7)$$

and the known solutions corresponds to $D=0$. For non zero values of D it is believed that solutions involve elliptic integrals and finite solutions do not exist. Author has given a class of F-solutions which correspond to $D=1/12$, and have oscillatory behaviour near the origin; indeed the period of oscillation grows indefinitely as ξ tends to zero[7]. Author has calculated values of θ, u and v for a few values of ξ. Further it has been shown that all classes of M-solutions can be directly derived from the corresponding F-solutions and vice versa by substitution

$$z=iy \qquad ..(8)$$

It has also been shown that all classes of physically significant M-solutions and insignificant F-solutions are confined to the inequality

$$144\ D^2-1<0. \qquad ..(9)$$

Similar to $(u; v)$—variables, y and z defined as

$$y=-\xi^{\frac{n+1}{n-1}}\frac{d\theta}{d\xi}-\frac{2}{n-1}z\ ;\ z=\xi^{\frac{2}{n-1}}\theta, \qquad ..(10)$$

reduce the Lane-Emden equation to that of a first order. It has been believed that every point in the positive half plane, including the points on the y-axis, has a physical relevancy; but author has shown that neither the origin, nor the points on the negative y-axis have any physical relevancy[12].

Author's mentioned investigations are given in chapter II and III of the thesis. In the fourth chapter, in the light of the new concept of the structure of polytropic configurations given in the 3rd chapter, the structure for $n=5$ has been studied.

In the last chapter a few minimal problems of stars have been studied. It has been shown that the known solution of the Lane-Emden equation for $n=0$ with a slight change in the value of constant α introduced to connect r and ξ, represents a liquid star which one may get by putting $\rho=$constant directly in equations of hydrostatic equilibrium; and the solution given in (4) corresponds to n tending to zero and governs a gaseous star in which a $(P; \rho)$—relation of the kind

$$\rho=P^{\varepsilon} \qquad ..(11)$$

subsists where ε is an arbitrary quantity[13]. In such spheres both pressure and density simultaneously tend toward constancy. Such spheres have been termed as uniform spheres. Solutions of

$$\frac{u}{v}\frac{dv}{du}=-\frac{(n+1)-v-(n+1)u}{3(n+1)-nv-(n+1)u}, \qquad ..(12)$$

and

$$\frac{U}{V}\frac{dV}{dU}=-\frac{nU+V-n}{n(U+V-3)}; \qquad ..(13)$$

where

$$v=-4\pi\,GK^{-\frac{2n}{n+1}}\frac{r\rho^{\frac{2n}{n+1}}}{\rho'}\ ;\ v=-\frac{r\rho'}{\rho} \qquad ..(14)$$

and

$$U = -\frac{4\pi nG}{K(n+1)} \cdot \frac{r\rho^{2-\frac{1}{n}}}{\rho'}; \quad V = -\frac{r\rho'}{\rho}, \qquad ..(15)$$

for $n=0$ and -1 correspond to n tending to zero and minus one in our pressure density relation and these solutions govern the distribution of physical variables in a uniform sphere[14].

As regards the possibility of the existence of solutions expressing P and ρ as functions of r, the picture is as follows: Solutions of (12) for $n=0$ and -1, lying in the positive quadrant ($u \geqslant 0$; $v \geqslant 0$) contain only such parts of (r; P)—solutions which have physical meaning and from these solutions, even if P is known as explicit functions of r, ρ as a function of r cannot be derived. Solutions of (2) for $n=0$ and -1, lying in the positive quadrant ($U \geqslant 0$; $V \geqslant 0$) correspond to parts of (r; ρ)—solutions which are meaningful, and from these solutions even if ρ is known as functions of r, P as a function of r cannot be derived. Thus it was shown that solutions of (12) and (13) carry different physical meanings. This is the reason that solutions (4) and (5) are not expressible in (U; V)—plane. Eddington's upper limit to central temperature and density[12] has been reviewed.

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ON THE MORTALITY AMONGST YOUNG BUFFALO CALVES IN STATE FARMS—STATISTICAL AND PATHOLOGIC STUDIES*

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Studies on the mortality amongst buffalo calves were intended to find out the pattern of mortality, pathoanatomy and also the probable aetiological agents involved in various diseases.

The statistical analysis of the last five years data of 10 State Farms was done The data, for D.D.D. Farm, Mathura during the period of observation (March, 1967 to February, 1968) by the author were also analysed. Sixty buffalo-calves were autopsied and the significant lesions recorded. The tissues of brain, heart, liver intestines, prescapular lymphnodes and also from the organs showing gross lesions were utilised for histopathology. Special staining techniques viz. Weigert Pal and Cajal's Sublimate Gold were employed for the detailed study of neuropathology. Demonstration of bacteria, connective tissue, fat and fungus in tissue sections was also carried out. Bacteriological isolation of 42 calves was done with the colaboration of the Department of Bacteriology. The studies on biochemical aspects were confined to the determination of serum vitamin-A level and different serum protein fractions.

From the statistical analysis it was revealed that the aggregate mortality percentage from survey data was 24·57, while from observation data it was 44·89. Gastro-intestinal disorders were the main causes of heavy mortality. The autumn and winter seasons were most enimical to the calves in their young life.

Gross and histopathologic investigations alongwith bacteriological findings revealed that out of 60 calves, 45 were affected with CBCS (coli bascillosis and coli septi caemia) syndrome. The various manifestations of this syndrome recorded and described were: gastro enteritis (24), meningo-encephalitis (8), pneumonia (5), peritonitis (4), omphalophlebitis alongwith arthritis (2) and nephritis (2). Amongst the miscellaneous conditions, phenothiazene poisoning

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(2), hepatoencephalopathy (5), myocardial degeneration (3) and 1 for each of sunstroke, snakebite and chronic cellulitis, were noticed. One case of cholengioma in a 6 months old calf was also recorded.

Reduction in gammaglobulin and Vitamin-A levels of serum was marked in calves affected with CBCS syndrome especially with the manifestations of gastro-enteritis and meningo-encephalitis.

Conclusions on the pathology of buffalo calf mortality were drawn from the correlation of pathoanatomic, bacteriologic and biochemical investigations.

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CYTOCHEMICAL, HISTOCHEMICAL AND BIOCHEMICAL STUDIES IN PROGRESSIVE EXPERIMENTAL ORAL CARCINOGENESIS OF HAMSTER CHEEK POUCH AND PALATE WITH D. M. B. A. (9,10-DIMETHYL 1, 2-BENZANTHRACENE)

VED PRAKASH BHARADWAJ

SUMMARY

Tumours of the oral cavity are the commonest malignant tumours in this part of the country. Epidemiological studies have revealed that the incidence of this disease is higher than any of the reported incidence rate in other parts of the world.

For understanding the process it is imperative to study the evolutionary changes taking place as the tissue changes from normal to neoplastic state through various successive stages and to develop methods for their detection at the earliest. Since the vast majority of Indian population living in rural areas is inaccessible for follow up, the study of this kind is impracticable and endowed with self-imposed limitations. Therefore, the present model of DMBA induced experimental oral carcinogenesis designed in hamster cheek pouch and palate seems to provide an opportunity to study the detailed cytochemical, histochemical and biochemical changes in various stages of the progressive experimental oral carcinogenesis.

The importance of cytochemical and histochemical study lies in the fact that it may clarify some of the problems related in the development of the malignant oral epithelium and also in its early detection before morphological changes are discernible. Further importance of the study lies in the fact that it enables the assessment of dynamic changes of cytochemical organisation in different functional stages. It also makes possible to establish the role played by different cellular components in the metabolic process of the cell.

The problem of biochemical uniformity or heterogenecity of proteins of normal and malignant tissues have also attracted the attention of various workers and a number of observations from some recent studies lend support to the

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metabolic uniformity of tumour tissue proteins. The application of electrophoretic technique in study of tumour tissue proteins have provided a new approach to the problem. These studies carried out through electrophoretic procedure are bound to provide differentiation of the molecular species constituting the body of the cells and thus may provide deeper insights into the metabolic fluxes related to anabolism and differentiation of cytostructure.

The work reported here consists of :—

1. Cytochemical and histochemical studies.
2. Biochemical studies.

Cytochemical and Histochemical Studies

Hamster cheek pouch and palate were painted with 0·5 per cent solution of DMBA in acetone. The following non-enzymatic and enzymatic reactions were studied, both cytochemically and histochemically:—

Non-enzymatic Reactions

—D.N.A.
—D.N.A. and R.N.A.
—SH Groups.

Enzymatic Reactions

—Succinic Dehydrogenase
—Alkaline Phosphatase
—Acid Phosphatase.

(1) Feulgen reaction was used for the cytochemical and histochemical demonstration of DNA. The semiquantitative assessment of the reaction revealed that the DNA activity in basal and parabasal cells was most intense. In advanced stages of dyskaryosis and malignancy this activity was most pronounced. The cytochemical findings were corroborated with the histochemical observations. The present study revealed that the increase in DNA content is an important feature observed during progressive experimental oral carcinogenesis.

The theoretical significance of DNA activity with reference to the biology of replication of the nuclei and genetic apparatus is discussed.

(2) The DNA/RNA studies were carried out by using methyl green-pyronin staining. The cytochemical and histochemical observations of DNA activity as revealed through methyl green staining were similar to those, encountered in Feulgen reaction. The presence of RNA in cytoplasm and nucleolus was confirmed by the cytochemical and histochemical studies. The exfoliated intermediate and parabasal cells were rich in RNA activity. The semiquantitative assessment revealed an increase in the activity of RNA during progressive oral carcinogenesis. The cytochemical studies were in accordance with the histochemical findings.

The participation of RNA of cytoplasm and the nucleolus in the protein synthesis has been discussed with reference to the observations in the present study and to the problems of carcinogenesis in general.

(3) The DDD method was used for the demonstration of protein bound SH groups. The superficial and parabasal cell types were found rich in SH group activity. In tissue sections for histochemical studies the concentration of the SH groups was found most pronounced in the basal cell layer and in stratum corneum. The semiquantitative assessment of the SH group activity revealed a progressive rise with the advancing stages of carcinogenesis.

An analysis of the SH group activity during the progressive stages of carcinogenesis, suggested that it played important role(s) in the cell growth and function especially as associated with experimental carcinogenesis.

(4) The Nitro-BT method was used for the demonstration of succinic dehydrogenase activity. The normal intermediate and parabasal cells were found rich in this activity. It was observed to be almost entirely confined to the cytoplasm. In sections the concentration of succinic dehydrogenase activity was found to be highest in the basal cell layer. In well differentiated carcinomas the cells at the periphery of invading columns showed increased activity, while those towards the centre or near the keratin pearls did not show any significant grades of activity. The semiquantitative assessment of the enzymatic activity revealed a progressive rise with the advancing stages of carcinogenesis.

The observations of the pattern and intensities of succinic dehydrogenase activity revealed that the energy yielding metabolic reactions mediated by the enzyme are significant in the biological cellular processes of growth and cell modutations, involved during experimental oral carcinogenesis.

(5) The alkaline phosphatase activity was demonstrated by using azo dye coupling method. The Kaplow's technique was used for the semiquantitative assessment of the enzymatic activity in the exfoliated cells. In normal smears the score count values were highest in parabasal and intermediate cell types. During the advancing stages of carcinogenesis, these score values increased progressively. In parabasal cells the variation of the score counts value from the normal range was found statistically highly significant in comaprison to the values observed in other cell types. In tissue sections for histochemical studies, the enzymatic activity was found progressively increased in stratum malpighi and basal cell layers with the advancing stages of carcinogenesis. The histochemical findings in the present study revealed the presence of stromal alkaline phosphatase activity in normal tissue sections, which was most pronounced in tumours.

These observations suggested that the biological reactions involved in the differentiation of normal cells or the growth of cancer cells are significantly associated with and/or dependent on the presence of alkaline phosphatase.

(6) The azo dye coupling method was used for the demonstration of acid phosphatase activity. The Kaplow's technique was used for the semiquantitative assessment of its activity in the exfoliated cells. The increase in the score count values of superficial, intermediate and parabasal cells, during the progressive stages of carcinogenesis were found statistically significant.

In tissue sections the activity was present in stratum corneum, stratum malpighi and basal cell layer, which showed a progressive rise during progressive experimental carcinogenesis. In epidermoid carcinomas, the keratinized layers of the pearls showed pronounced activity.

An analysis of the acid phosphatase activity during the progressive stages of carcinogenesis showed that it was related to the processes associated with the development of keratinization and/or other similar features associated with carcinogenesis.

(7) The cytochemical and histochemical findings observed in the present study were compared with the cytomorphological and histomorphological observations (unpublished data) and two facts were emphasized viz. (i) that the cyto- and histochemical procedures are far more sensitive methods for qualitatively and quantitatively indicating any change(s) in the cells and tissues and; (ii) that the subtle changes in the realm of biochemical composition starts fairly early during the process of carcinogenesis, which only at a far later stage summates upto the levels, recognisable by routine microscopy.

Biochemical Studies

(i) Fourtyseven homogenates of hamster cheek pouch were examined by electrophoresis for their protein components. This total number of 47 cases consisted of 9 cases showing normal histological features, 14 cases with submucous fibrosis, 4 cases showing intraepithelial carcinoma and 20 cases of epidermoid carcinoma of the hamster cheek pouch.

(ii) The tissues from the cheek pouch showing normal histological features as well as tissues showing submucous fibrosis and epidermoid carcinoma, consisted of seven distinct electrophoretically separable fractions.

(iii) A comparison of mobilities of these seven tissue fractions with that of serum protein fractions showed a fast moving fraction I, similar in mobility with that of albumin. It was also observed that fractions II, III and IV occupied the zone of alpha-I, alpha-II globulins and fractions V, VI and VII somewhat coincided with the zones of beta and gamma globulins.

(iv) A comparison between the mean values of individual fractions of normal cheek pouch with those found in the tissues at various stages of progressive carcinogenesis, i.e. submucous fibrosis, intraepithelial carcinoma and epidermoid carcinoma has been done. A significant variation was observed in fractions II, III and IV. The fraction II showed decrease and fractions III and IV an increase during the progressive stages of DMBA induced carcinoma.

(v) Slight decrease of fraction II in submucous fibrosis and marked decrease in intraepithelial carcinomas has been correlated with the decrease of superficial cell types, which was observed in higher grades of dyskaryosis and in stage of intraepithelial carcinoma.

(vi) It has been suggested that quantitative increase in fractions III and IV in the stages of submucous fibrosis and intraepithelial carcinoma could be correlated with the increase in basal and dyskaryotic cells, which are rich in nucleoproteins.

(vii) The electrophoretic study of the serum proteins was carried out in a total number of 15 hamsters, out of which 3 belonged to normal control group, 2 were showing submucous fibrosis and 10 were having frank epidermoid carcinoma.

(viii) The electrophoretic pattern of the hamster serum proteins during the various stages of progressive carcinogenesis consistantly revealed the presence of five distinctly separated fractions corresponding to the albumin; alpha-I, alpha-II, beta and gamma globulins of the human serum.

(ix) It was observed that during the progressive stages of carcinogenesis, albumin fraction decreased in submucous fibrosis and invasive carcinoma, being more marked in the later.

(x) The alpha-I and alpha-II globulins showed a marked increase in the submucous fibrosis and carcinoma. It is suggested that this increase could occur as a sequence of decreased albumin levels in these stages.

(xi) The beta and gamma globulins were also found to be increased in submucous fibrosis and malignancy. It is suggested that the increase in the gamma globulin in submucous fibrosis and malignancy might be either due to an abnormal protein secreted by the malignant cells or due to a type of immunological response on the part of host towards the malignant cells or their breakdown products.

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THE EFFECT OF ELASTICITY AND DENSITY ON THE PRESSURE DEPENDENCE OF MÖSSBAUER RECOILLESS FRACTION

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INTRODUCTION

The effect of pressure on recoilless fraction of gamma rays 'f' has been reported by Hanks[5] and Mahesh[8]. This important parameter is sensitive to lattice properties of the solid. These authors have investigated the theoretical behaviour of f-P variations by introducing the Grüneisen constant and compressibility factor in their calculations.

In this article, we have attempted to investigate the f-P variations entirely from a different angle by introducing the mean square displacement of the recoilling nucleus from Lindemann relation and have shown that these variations depend upon the corresponding change of elasticity and density of the solid with pressure. The enhancement in 'f' with pressure is found to depend not only upon the compressibility β but is more effectively influenced by the pressure coefficient of elasticity of the solid.

THEORETICAL

The recoilless fraction 'f' is expressed as[10],

$$f = \exp\left[-K^2 \langle x^2 \rangle\right] \qquad \ldots(1)$$

where $K = \frac{E}{\hbar c}$, E is gamma ray energy and $\langle x^2 \rangle$ is the component of the mean square vibrational amplitude of the emitting nucleus in the direction of the gamma rays.

Let us define a parameter γ used by Lindemann in the melting criteria of solids. This parameter γ relates the mean square displacement of the atoms $\langle \delta R_1^2 \rangle$ and the square of the interatomic distance R_0^2 as[9],

$$\gamma = \frac{\langle \delta R_1^2 \rangle}{R_0^2} \qquad \ldots(2)$$

Thus,

$$\langle \delta R_1^2 \rangle = 3 \langle x^2 \rangle = \gamma R_0^2$$

or,

$$\langle x^2 \rangle = \frac{\gamma R_0^2}{3} \qquad \ldots(3)$$

eq. (1) with the help of eq. (3) can be written as,

$$\log f = -\frac{E^2 \gamma R_0^2}{3 \bar{h}^2 c^2} \qquad \ldots.(4)$$

near Absolute Zero γ is given by[9],

$$\gamma = \frac{3 \bar{h} K_D^2 L^3}{8 \pi^2 M N S R_0^2} \qquad \ldots.(5)$$

here S and M are mean sound velocity and mass of the atom respectively, K_D is wave vector defined by[9],

$$\left.\begin{aligned} h\, S\, K_D &= k\, \theta_D \\ \text{and,} \quad K_D^3 &= \frac{6 \pi^2 N}{L^3} \end{aligned}\right\} \qquad \ldots.(6)$$

where θ_D is Debye temperature expressed as[1],

$$\theta_D = \frac{h}{k} \left(\frac{3}{4} \frac{p}{\pi} \frac{N\rho}{m} \right)^{\frac{1}{3}} S \qquad \ldots.(7)$$

In this ρ, m and p are density, molecular weight and atomicity respectively.

Using eqs. (5), (6) and (7); eq. (4) can be written as,

$$\log f = -\frac{3 E^2}{4 M c^2 h \left(\frac{3}{4} \frac{p}{\pi} \frac{N\rho}{m} \right)^{\frac{1}{3}} S} \qquad \ldots.(8)$$

This is the expression for 'f' near Absolute Zero.

From eq. (8) it is evident that the variation of 'f' with pressure P, in first approximation is therefore expected to be through the variation of ρ and S with P. Therefore eq. (8) at the pressure P may be written as,

$$\log f_P = -\frac{3 E^2}{4 M c^2 h \left(\frac{3}{4} \frac{p}{\pi} \frac{N\rho_P}{m} \right)^{\frac{1}{3}} S_P} \qquad \ldots.(9)$$

As the sound velocity is the square root of the ratio of modulus of elasticity and density, the mean sound velocity S may be expressed as,

$$S = \sqrt{\frac{C}{\rho}}$$

where C is the mean value of the modulus of elasticity. If we assume that the variation of C with P is similar to that of Young's modulus then,

$$S_P = \sqrt{\frac{C\,(1+AP)}{\rho(1+\beta P)}} \qquad \ldots.(10)$$

here β is compressibility and A is pressure coefficient of elasticity given by[3],

$$A = \frac{(3\lambda+5\mu)\,(\lambda+2\mu)}{\mu\,(3\lambda+2\mu)(\lambda+\mu)} \qquad \ldots.(11)$$

where λ and μ are Lame's elastic coefficients, Substitution of eq. (10) in eq. (9) would thus yield an expression for f-P variation near Absolute Zero as,

$$\log f_P \approx -\frac{3\,E^2}{4\,M\,c^2\,h\left(\frac{3}{4}\,\frac{p}{\pi}\,\frac{N\rho}{m}\right)^{\frac{1}{3}} S\,\left\{1+\frac{P}{2}\left(A-\frac{\beta}{3}\right)\right\}} \qquad \ldots(12)$$

here we have neglected higher order terms of A, β and the product Aβ, since A and β are very small.

Discussion

The pressure coefficient A has been calculated from the equation (11), substituting Lame's elastic coefficients[2], λ and μ. The parameters E, S, ρ and β have been taken from the standard data tables[4,1,6,7] and are given in Table 1 along with the calculated values of A. Values of f have been determined at different pressures (0-100, k—bar range) and are shown in Fig. 1. It could be observed that all the curves for various lattices are linear.

It may be noted from Fig. 1 that our results of f-P variations are in close agreement with those of Mahesh[8] except for Zn^{65} and Au^{197}. For Zn^{65} it is lower and for Au^{197} it is slightly higher. Since we have employed different criteria for calculations, some deviations are quite natural.

It can be observed from Table 1 that the value of A is greater than β and β comes as $\beta/3$ in the eq. (12). This proves that the variation of elasticity with pressure plays a more prominent role in the f-P variation.

TABLE 1

Values of E, S, ρ, β, and A

Radio-isotopes	E(kev.) (ref. 4)	S(Km/Sec.) (ref. 1)	ρ(gm/c.c.) (ref. 6)	β(per bar) ·10^6 (ref. 6, 7)	A(per bar) ·10^6 cal.
Fe^{57}	14·4	3·662	7·9	·59	2·71
Cu^{62}	41·6	2·627	8·96	·73	3·52
Al^{28}	32·0	3·638	2·7	1·37	6·82
Sn^{119}	24·0	2·021	7·3	1·8	8·91
Ag^{107}	93·0	1·950	10·5	1·0	5·79
Zn^{67}	93·0	2·701	7·1	1·7	4·93
Ni^{61}	67·4	3·542	8·0	·62	2·27
Au^{197}	77·0	1;391	19·3	·61	4·75
W^{183}	46·5	3·190	19·3	·32	1·29

SUMMARY

An expression of the recoilless fraction f has been derived and the effect of pressure on f is examined theoretically near Absolute Zero. An interpretation of the f-P variation is given on the basis of the variation of elasticity and density with pressure.

ACKNOWLEDGEMENTS

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MORPHOLOGICAL STUDIES IN THE ORDER UMBELLIFLORAE-UMBELLIFERAE—III. TRACHYSPERMUM ROXBURGHIANUM (DC.) CRAIB.

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INTRODUCTION

The family Umbelliferae since long, has attracted the attention of the morphologists. The previous literature on floral morphology and embryology has already been reviewed (Dhakre, 1964, 1968; Gupta, 1964; and Sehgal, 1965). *Trachyspermum roxburghianum* is found growing wild and is also cultivated. The dry seeds of this plant are taken as a substitute for common omum (*Trachyspermum ammi*) for flavouring dishes, beverages, cakes and sauces.

The present work, in the floral morphology and embryology of *Trachyspermum roxburghianum*, constitutes a part of the scheme aimed at working out the development and structure of seeds and fruits of some of the Indian Umbelliflorae.

MATERIAL AND METHODS

The buds, flowers and fruits of *Trachyspermum roxburghianum* were fixed in formalin-aceto-alcohol, preserved in 70% alcohol. For microtomy the material was, treated in the customary manner. The serial sections were cut at 6-12 μ and stained with safranin and fast-green.

OBSERVATIONS

Flower—The flowers are minute and borne in compound umbels. All, excepting a few central flowers of the umbel which remain neutral are bisexual. The calyx is obsolete. The petals bear fine bristles and are white in colour. The stamens remain incurved in the bud but they spread out at the time of dehiscence. The epigynous disc develops at the top of the inferior, syncarpous and bilocular ovary. It is interesting to find an occasional flower arising out of the pedicel of another flower towards the close of the season. Anatomy of such umbels would throw some light on their real nature.

Organogeny—Floral primordium begins as a convex protuberance (Fig 1). Later on, the primordia of petals and stamens arise almost simultaneously followed by those of the carpels (Figs. 2,3). The primordia of carpels arise close to each other and their outer walls fuse early to form a unilocular, syncarpous ovary which is crowned by two styles. A small protuberance grows upward from the base of the ovarian cavity which partially divides the ovary into two chambers (Fig. 4). Two ovular primordia subsequently arise, one above the other, in each locule (Fig. 5), the lower one of these ovular primordia survives till maturity but the upper one aborts after the archesporial cell stage.

Floral anatomy—A cross-section of the pedicel shows four collateral vascular bundles almost in its centre (Fig. 6). They expand laterally during their upward course and fuse to form a vascular cylinder (Fig. 7). This vascular cylinder splits up into ten bundles (p_1, p_2...p_{10}) in the receptacle of the flower. Of these, p_1, p_2, p_3 and p_6, p_7, p_8 move towards the periphery (Fig. 8,9). The remaining four bundles (p_4, p_5 and p_9, p_{10}) also pass out leaving two groups of vascular elements, which constitute the ventral bundles of the carpels. The ventral carpellary traces split up into four bundles in the upper half of the septum (Fig. 10).

The ten traces in the peripheral region run length-wise parallel to the vittae and within the primary ridges (Fig. 10). The number of vittae, in each half of the ovary, is invariably more than six. The appendicular traces (*pt* and *st*), which are given out from the peripheral bundles in the upper part of the ovary, enter the petals and stamens in an alternate manner (Fig. 11). The petal is supplied by a single trace which sends out the lateral branches at different levels (Fig. 12). The stamen is a single trace structure (Fig. 13). The residual bundles (Fig. 15, rb_1, rb_2. . . .rb_{10}) then travel into the stylopodium and gradually disappear except six bundles which divide into two groups of three each and pass into each style (Fig. 16).

The ventral carpellary bundles become very conspicuous due to their lateral expansion in the upper half of the ovary. At this level, adjoining peripheral bundles (p_4, p_{10} and p_5, p_9) move towards the septum and anastomose with ventral bundles. The ovular traces originate from these fusion products (Fig. 14).

Microsporangium—The anther is tetrasporangiate. In each lobe of anther three or four archesporial cells differentiate in the hypodermal layer (Fig. 17). The archesporial cells divide periclinally to form a primary parietal layer and a primary sporogenous layer. The cells of the former undergo two periclinal (Figs. 18, 19) and many anticlinal divisions to produce single layer each of endothecium, middle layer and tapetum (Fig. 20). Thus their development follows the Dicotyledonous type (See Davis, 1966).

The tapetum is, however, distinguishable from its adjoining wall layers comparatively late. A part of the tapetum towards the connective is derived from the somatic cells (Figs. 19, 20). All cells of this layer at maturity become binucleate. In a limited number of cases the tapetum of some of the four sporangia become hypertrophied. The growth of the microspores in such cases is arrested rendering these microsporangia sterile (Fig. 21). The middle layer is crushed during the course of development of microsporangium (Fig.22). Endothecium develops characteristic fibrous thickenings (Fig. 23). The epidermis persists till maturity in a distorted condition.

Microsporogenesis--The primary sporogenous cells divide repeatedly to produce a mass of microspore mother cells. These cells undergo simultaneous type of divisions resulting in the formation of tetrahedral and decussate tetrads of microspores (Figs. 24-28).

Male gametophyte--A microspore at the time of its separation from a tetrad is a triangular structure. Gradually, it becomes ellipsoidal and develops a thick wall (Figs. 29-30). The first division of the nucleus results in the formation of a large vegetative cell and small generative cell (Fig. 31). The generative cell soon divides to form two male cells (Figs. 32-33). Later on, only one of the male cells moves towards the other pole, whereas the other remains stationary. Sehgal (1965) has reported that both the gametes remain on one side of the pollen grain in *T. ammi*. Movement of sperms has also been reported by Paliwal (1951) in *Coriandrum sativum*. Mature pollen grains are tricolporate and shed at three celled stage.

Megasporangium—The integumentary primordium, as well as, the female archesporium differentiate simultaneously (Fig. 34). The ovule curves (Fig 35) and becomes completely anatropous at binucleate stage of the embryo sac (Fig. 36). Some interesting changes are observed in the fertilized ovule which grows down considerably. The embryo sac also develops more rapidly in the lower region as compared to the upper part. As a result of this, the persistent antipodal cells are left midway in the direction of raphe (Figs. 37-38).

Megasporogenesis and female gametophyte—The female archesporium is 1 or 2-celled, but invariably only one of them enlarges and functions as megaspore mother cell (Figs. 39-40). As a result of meiotic divisions a linear tetrad of megaspores is produced (Figs. 41-42). Of these, only the chalazal one is functional (Fig. 43). Concurrently, the cells of the innermost layer of the integument become conspicuous by their larger size, denser cytoplasm and prominent nuclei. This layer thus serves as an integumentary tapetum (Figs. 44-45).

The functional megaspore enlarges in size and its nucleus undergoes three successive mitotic divisions giving rise to 2—, 4—, and 8—nucleate embryo sacs (Figs. 46-48) which lie in direct contact with the integumentary tapetum. The antipodal cells remain recognizable for a long time after fertilization (Fig. 38).

SUMMARY AND CONCLUSION

The flowers are minute and borne in compound umbels. These are bisexual except a few neutral flowers in the centre of each umbel.

The petals and stamens in *Trachyspermum roxburghianum*, arise almost simultaneously and are followed by the carpels.

The pedicel of the flower contains four collateral vascular bundles. These bundles split up into ten peripheral bundles and two centrally located groups of vascular tissues which form the ventral bundles of the carpels.

The placental traces originate from the fusion products of the ventral bundles and the adjoining peripheral bundles. The stylopodium is supplied by all residual bundles whereas the styles receive three traces each.

The microspore mother cells produce tetrahedral and decussate tetrads. The pollen grains are ellipsoidal and three-celled when shed. Rarely the tapetal cells are hypertrophied and cause sterility of microsporangia.

Two ovular primordia develop in each locule but only the lower one reaches maturity. The ovule is pendulous, anatropous, unitegmic and tenuinucellate.

One or two-celled female archesporium differentiates in the nucellus. The archesporial cell directly functions as megaspore mother cell. Embryo sac development conforms to the polygonum type.

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EXPLANATION OF FIGURES

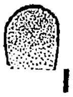
Plate I

Fig. 1–16. Organogeny and vascular anatomy of the flower of *Trachyspermum roxburghianum*.

Organogeny:

Fig. 1. Floral primordium—a longisection, 200X; Figs. 2-5. Developmental sequence of floral parts, all longisections, 200 X; Fig. 6. T.S. stalk of flower, 200 X; Fig. 7. T.S. base of receptacle of flower, 200 X; Figs. 8 & 9. T.S. floral receptacle showing departure of peripheral and ventral traces, 200 X; Fig. 10. T. S. flower showing peripheral bundles and a greater number of vittae than usual, 200 X; Fig. 11. T. S. same at a higher level showing departure of appendicular traces, 170 X; Fig. 12 & 13. Petal and stamen showing their vasculature, 83 X and 70 X respectively; Fig. 14. T.S. flower, origin of ovular traces, 170 X Fig. 15. T. S. stylopodium with residual bundles, 170 X; Fig. 16. T. S. styles, 200 X.

cp—carpel primordium; *pp*—petal primordium; *sp*—stamen primordium. $P_1 P_2 \ldots\ldots P_{10}$—Peripheral traces; $rb_1\, rb_2 \ldots\ldots rb_{10}$—residual bundles.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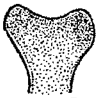
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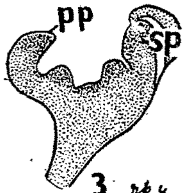

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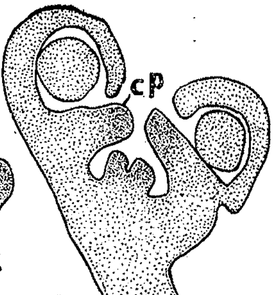

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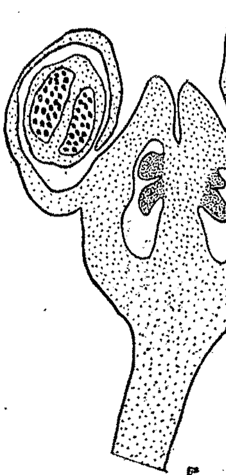
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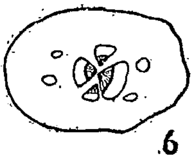
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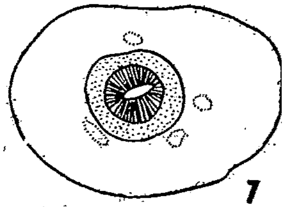
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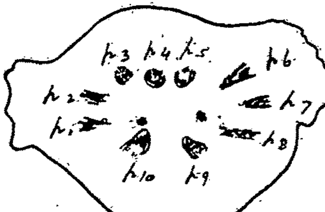

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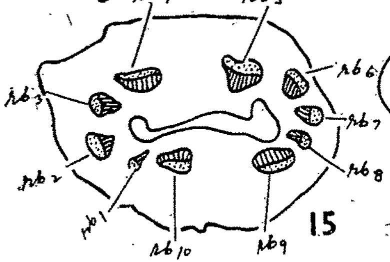

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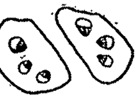
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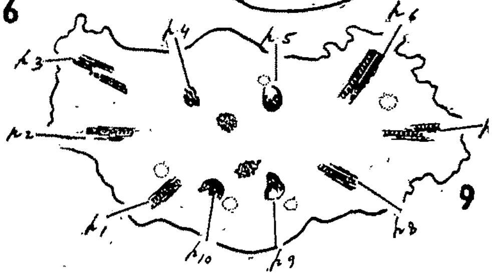

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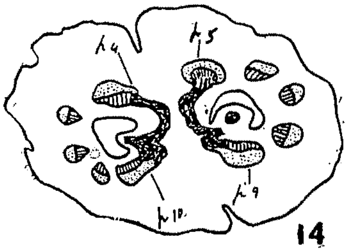

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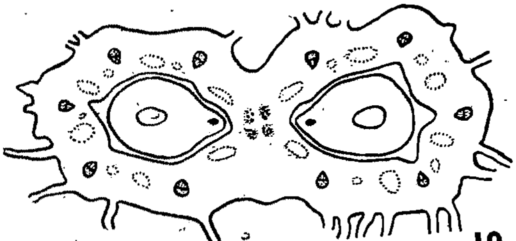
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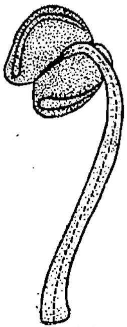
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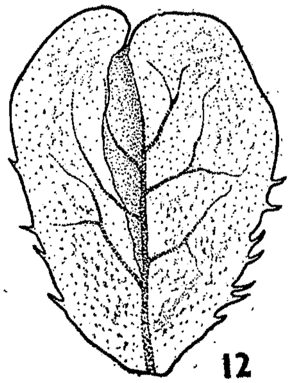
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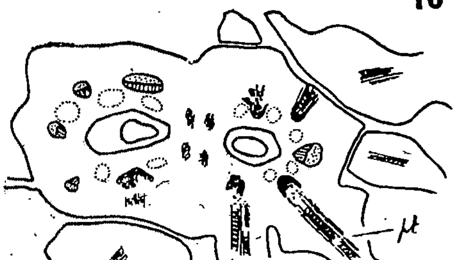

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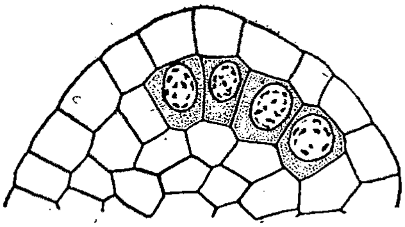
Plate II

Figs. 17–33. Microsporogenesis and microgametogenesis. Figs. 17–20 & 25–29. Stages in microsporogenesis, 1900 X; Fig. 21. T. S. anther with fertile and sterile sporangia, 470 X; Figs. 30–33. Stages in the development of male gametophyte, 1900 X.

nal—normal anther lobe; *sal*-male—sterile anther lobe.



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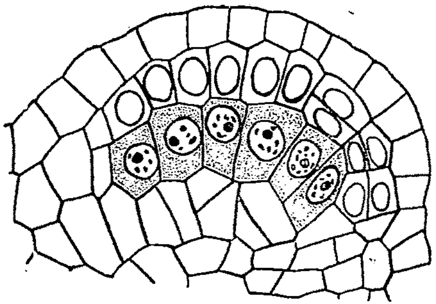

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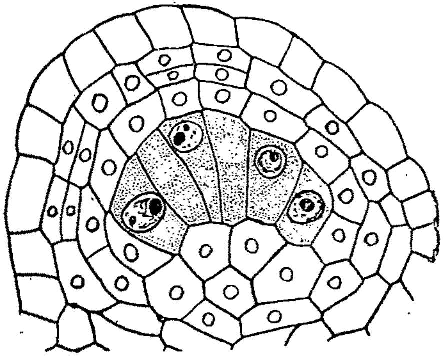

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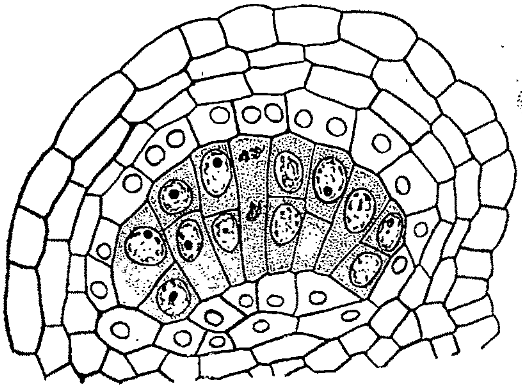

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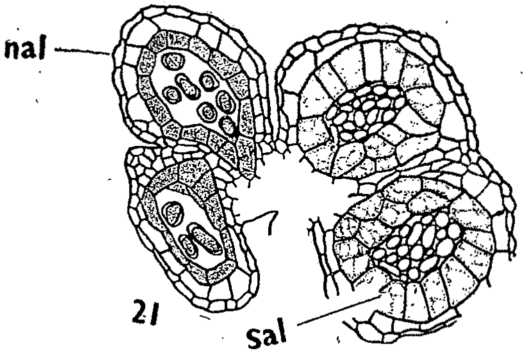

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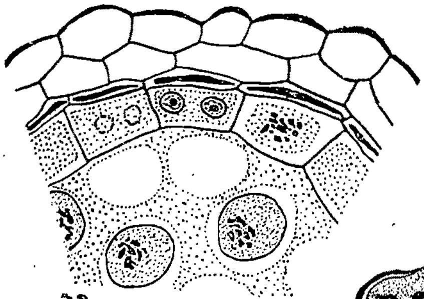

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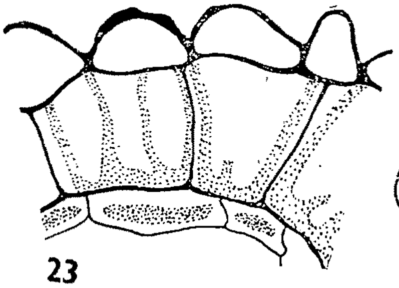

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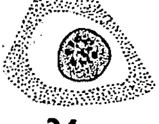

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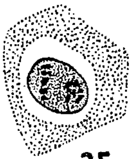

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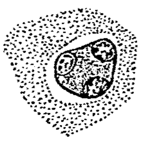

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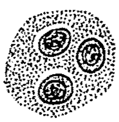

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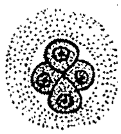

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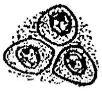

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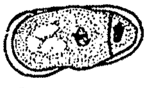

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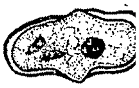

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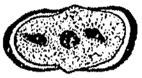

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Plate III

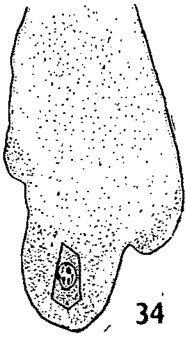
Figs. 34–48. Development of ovule and female gametophyte.

Figs. 34–38. Different stages of development of ovule (34–910 X; 35 & 36–750 X; 37—300 X, 38—200 X.)

Figs. 39–43. Megasporogenesis. 1900 X.

Figs. 44–48. Stages in the development of female gametophyte. Note the endothelium in Figs. 44–45. 910 X (46—1900 X; 47—1257 X, 48—910 X).

Note:—The magnifications of figures 1—48 are written in original. These should be taken as reduced by 1/3.



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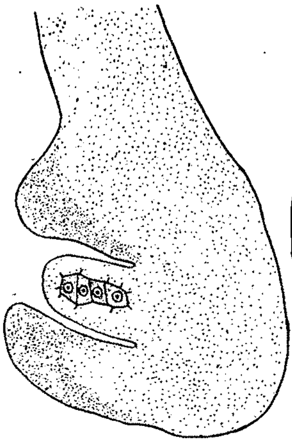

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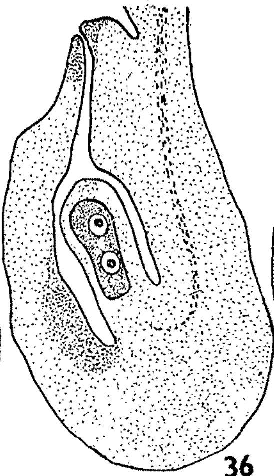

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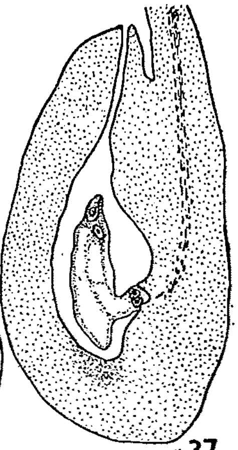

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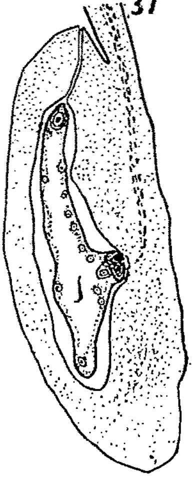

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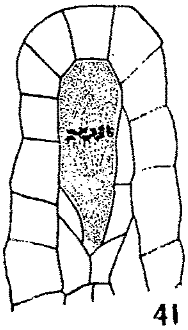

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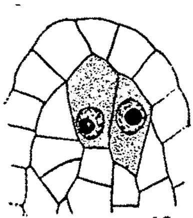

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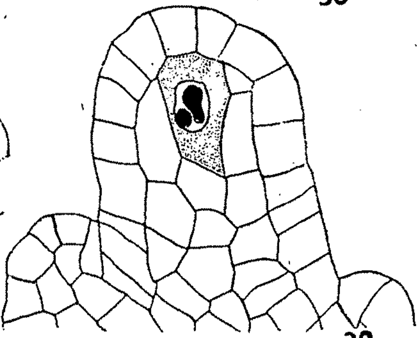

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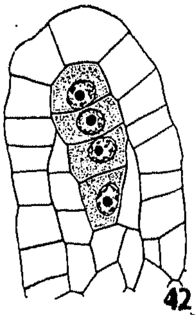

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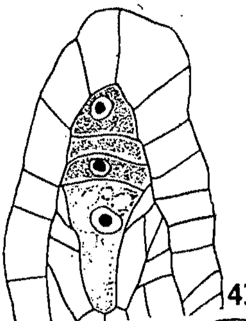

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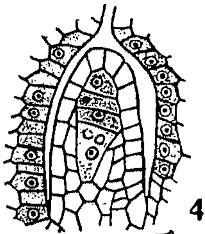

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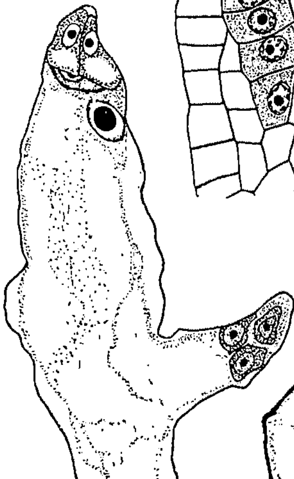

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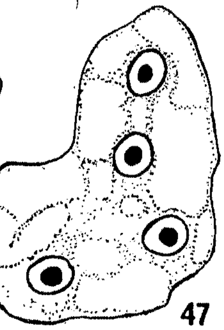

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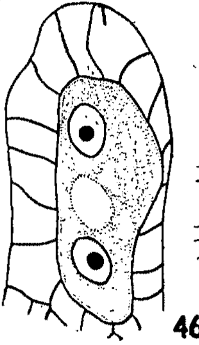

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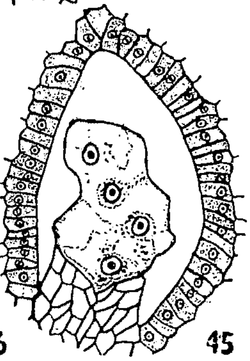

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NORMAL DIFFERENTIAL LEUCOCYTE COUNT IN POULTRY

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Introduction

Sufficient published data in India on haematological norms in poultry are not available. The results obtained in foreign countries can not be applied as such, because of the variable factors like heredity, diet, climatic conditions and topography etc., which are likely to introduce considerable variations in different blood constituents of the animals.

It was, therefore, of interest to study the normal leucocyte count in healthy chickens; so that basis for future studies on pathological changes in circulating leucocytes, if any, in poultry disease may be formed under the existing conditions.

Materials and Methods

Three hundred and seventyone adult, healthy birds of different breeds, as detailed below, aged 1 to 2 years, were used in the present study.

Sl. No.	Breed	Sex	Total no. of birds
1.	Rhode Island red (RIR)	Male	16
2.	Rhode Island red (RIR)	Female	75
3.	White Leghorn (WL)	Male	34
4.	White Leghorn (WL)	Female	225
5.	New-hampshire (NH)	Female	6
6.	Black-Minorca (BM)	Female	9
7.	White cornish (WC)	Female	6

The birds belonged to the poultry farm attached to the College. All of them were apparently healthy and about 30% of the female stock of the poultry farm was in laying at the time of study. All the birds had been dewormed only a month ago and faecal examination was negative for any type of worm infection. The birds were being fed, adlibidum, the mash of the following composition:—

Barley	500 kg.
Wheat Bran	250 kg.
Ground nut cake	250 kg.
Fish meal	100 kg.
Mindif	20 kg.
Vitamix (Pfizer)	2·5 kg.

In addition, green lobia and boiled meat offals were also given at the rate of 50 gm. and 15 gm. per bird respectively at about 11·30 a.m. daily. The birds were maintained under deep litter system with ideal farm conditions.

The experiment was conducted at Mathura which is about 450 feet above the sea level. The annual air temperature ranges from 37°F to 118°F and the average rainfall is about 80 cm. with hot-dry climate. The blood smears were prepared in the first week of July, 1967, between 8 to 10 a.m. daily.

Blood smears were prepared and stained according to the method recommended by Lucas and Jamroz (1961). The criterian used for differentiation of leucocytes were as described by Lucas and Jamroz (loc.cit.).

Standard deviation, standard error, coefficient of variation and 'T' values were calculated according to the methods described by Snedecor (1961).

RESULTS

The data on the differential leucocyte count in the different breeds of poultry as observed in this study with range, mean values, their standard deviation and coefficient of variation, have been presented in table 1.

Average values of heterophils, eosinophils, basophils, lymphocytes and monocytes have been depicted by bar-diagrams (Fig. 1).

The results were statistically analysed by the method of 'T' test and the findings are shown in table 2.

DISCUSSION

High variability in the cell count of poultry blood has been reported by several workers (Palmer and Biely, 1935; Olson, 1937; Natt and Herrick, 1954; Diesem *et al.*, 1958 and Lucas and Jamroz, 1961). Similar observations have been made with the cell counts of blood samples taken from mammals (Ferguson *et al.* 1945; Garrey and Bryan, 1935 and Sturgis and Bethell, 1943). It can be summarised that the problems and principles involved are equally applicable to the different species. The data reported in this study (Table 1) also conform to the findings of the above cited workers, in so far as the differential leucocyte count of the poultry is concerned.

TABLE 1

Differential Leucocyte Count in Different Breeds of Poultry with Range, Mean Values, Their Standard Deviation and Coefficient of Variation

Sl. No.	Breed	Sex	No. of birds under study	GRANULOCYTES											
				Heterophil				Eosinophil				Basophil			
				Range %	Mean %	S.D. ±	C.V. %	Range %	Mean %	S.D. ±	C.V. %	Range %	Mean %	S.D. ±	C.V. %
1.	RIR	Male	16	25·00 to 60·75	35·87	9·42	26·50	1·75 to 4·25	2·80	0·71	25·36	1·25 to 4·25	2·50	0·72	28·98
2.	RIR	Female	75	15·00 to 61·25	33·30	4·27	12·80	0·75 to 3·75	1·60	0·72	45·05	0·75 to 5·00	2·20	0·99	45·10
3.	WL	Male	34	15·50 to 55·00	27·10	7·57	27·90	0.75 to 3·25	1·88	0·62	32·90	1·00 to 4·75	2·50	0·83	33·54
4.	WL	Female	225	15·50 to 49·75	28·49	1·40	4·90	0·75 to 3·75	1·95	0·75	38·60	0·75 to 4·50	2·17	0·80	36·90
5.	NH	Female	6	20·50 to 35·50	26·70	5·57	20·80	1·25 to 3·75	2·66	0·97	36·20	1·25 to 3·25	2·05	0·76	37·30
6.	BM	Female	9	23·00 to 42·50	29·90	6·40	21·43	0·75 to 5·00	2·88	1·66	57·60	2·25 to 5·00	3·00	0·86	28·86
7.	WC	Female	6	14·50 to 41·50	27·20	9·10	33·80	1·50 to 3·50	2·50	1·10	44·00	1·25 to 3·75	2·50	0·86	34·64

(Continued)

TABLE 1 (*Contd.*)

Sl. No.	Breed	Sex	No. of birds under study	AGRANULOCYTES							
				Lymphocyte				Monocyte			
				Range %	Mean %	S.D. ±	C.V. %	Range %	Mean %	S.D. ±	C.V. %
1.	RIR	Male	16	26.75 to 67·50	52·46	10·77	20·53	2·50 to 13·75	6·40	4·18	65·36
2.	RIR	Female	75	29·75 to 75·50	58·10	9·33	16·07	1·75 to 9·25	4.63	1·60	34·70
3.	WL	Male	34	33·75 to 77·50	62·50	8·18	13·15	3·25 to 9·25	6·27	1·83	29·20
4.	WL	Female	225	40·50 to 76·50	62·00	4·05	6·53	2·25 to 10·25	5·37	1·67	31·40
5.	NH	Female	6	55·00 to 70·25	62·80	5·32	8·40	3·50 to 7·50	5·66	1·72	30·40
6.	BM	Female	9	43·00 to 67·50	58·60	8·10	13·90	3·25 to 8·75	5·77	1·90	33·06
7.	WC	Female	6	48·25 to 77·50	62·40	9·33	14·90	3·00 to 9·50	5·20	2·48	47·80

S.D.=Standard deviation; C.V.=Coefficient of variation

TABLE 2

'T' Values for Leucocytes Count

Sl. No.	Group	Differential Leucocyte Count				
		Heterophil	Eosinophil	Basophil	Lymphocyte	Monocyte
1.	RIR male × WL male	3·27*	4·45*	0·00	3·21*	0·12
2.	RIR male × RIR female	1·07	6·12*	1·40	1·91	1·66
3.	RIR female × WL female	9·57*	3·63*	0·23	3·50*	6·19*
4.	RIR female × NH female	2·83*	2·64*	0·45	1·93	1·41
5.	RIR female × BM female	1·55	2·28*	2·57*	0·17	1·74
6.	RIR female × WC female	1·53	1·97	0·82	1·08	0·55
7.	WL male × WL female	1·07	0·59	2·15*	0·14	2·69*
8.	WL female × NH female	0·78	1·78	0·37	0·36	0·40
9.	WL female × BM female	0·65	1·67	2·82*	1·24	0·61
10.	WL female × WC female	0·34	1·16	0 92	1·10	0·16
11.	NH female × BM female	1·02	0·32	2·23*	1·20	0·11
12.	NH female × WC female	0·11	0·27	0·97	0·91	0·37
13.	BM female × WC female	0·62	0·53	1·09	0·81	0·47

* Significant (PL < 0·05)

According to this study significant differences ('T' test) were obtained between the leucocyte values of different groups of birds (Table 2). These findings are not in agreement with those of Verma (1960), who reported non-significant differences between males of different breeds and male and female of the same breed. Lucas and Jamroz (loc. cit.) on the other hand observed a statistically significant difference between the means for each line on almost every type of blood determination; the only values not significantly different were eosinophil averages. The significant differences in eosinophil values presented in this study might be due in part to the criterion used in the identification of heterophils and eosinophils. As both these cells stain acid in reaction the difference in the shape of their respective cytoplasmic granules has been the main criterion for distinguishing the heterophil from the eosinophil. The shape of the granules of heterophil shows extreme variations from rod shaped or spindle like to a definite spherical shape. It is, because of this variation that the differentiation of the heterophil granules from the typical spherical granules of the eosinophil at times, becomes quite difficult (Natt and Herrick, 1954; Diesem *et al.*, 1958).

The findings that the percentage values for eosinophils and basophils do not differ widely in different sexes and that the average values of monocytes are higher in male than in female, are supported by the observations of Olson (1965). Coefficient of variation, however, is highest in monocytes followed by eosinophils and least in basophils, indicating high variability within birds in respect of monocytes rather than in eosinophils and basophils.

Lucas and Jamroz (loc. cit.) reported that female chickens showed a higher percentage values for lymphocytes than did male chickens. The reverse was true for heterophils. While the data for RIR birds presented in this study conform to the above findings, that for WL species are different, in that the average values for these two types of leucocytes are almost same for both male and female.

Although the average values of heterophils in RIR in this study have been found a bit lower than that reported by Verma (Loc. cit.) and Lucas and Jamroz (loc. cit.), the values of heterophils in WL are in close agreement with those of Lucas and Jamroz (loc. cit.); Olson (1937) and Twisselmann (1939). The values of heterophils in NH breed (26·7%) are also similar to those recorded by Bruceglick (1957).

The average lymphocyte values of RIR reported here are higher than those reported by Verma (loc. cit.), but are in close agreement with those reported by Lucas and Jamroz (loc. cit.). In WL breed the lymphocyte values (62·2% for male and 62·0% for female) are midway of those recorded by Verma (loc. cit.) and Lucas and Jamroz (loc. cit.).

On the perusal of the literature available to us it appears that perhaps work has not been concentrated to establish the normal values of differential leucocyte count in such breeds as BM and WC; hence results of this study could not be compared. When compared, however, with the respective values in other breeds, in general, the average percentage values of different leucocyte types in BM and WC do not appear to differ much, except that the count of basophils in BM is a little higher than that in other breeds. Significant differences also exists between BM×RIR, WL and NH as regards basophil. In absence of available literature this difference of basophil values in BM can not be further explained at this stage and needs further investigation.

SUMMARY

The normal differential leucocyte count in different breeds of poultry has been studied and the data obtained have been statistically analysed and discussed.

ACKNOWLEDGEMENT

The authors are grateful to Sri C.V.G. Choudary, Principal, U.P. College of Veterinary Science and Animal Husbandry, Mathura, for providing facilities.

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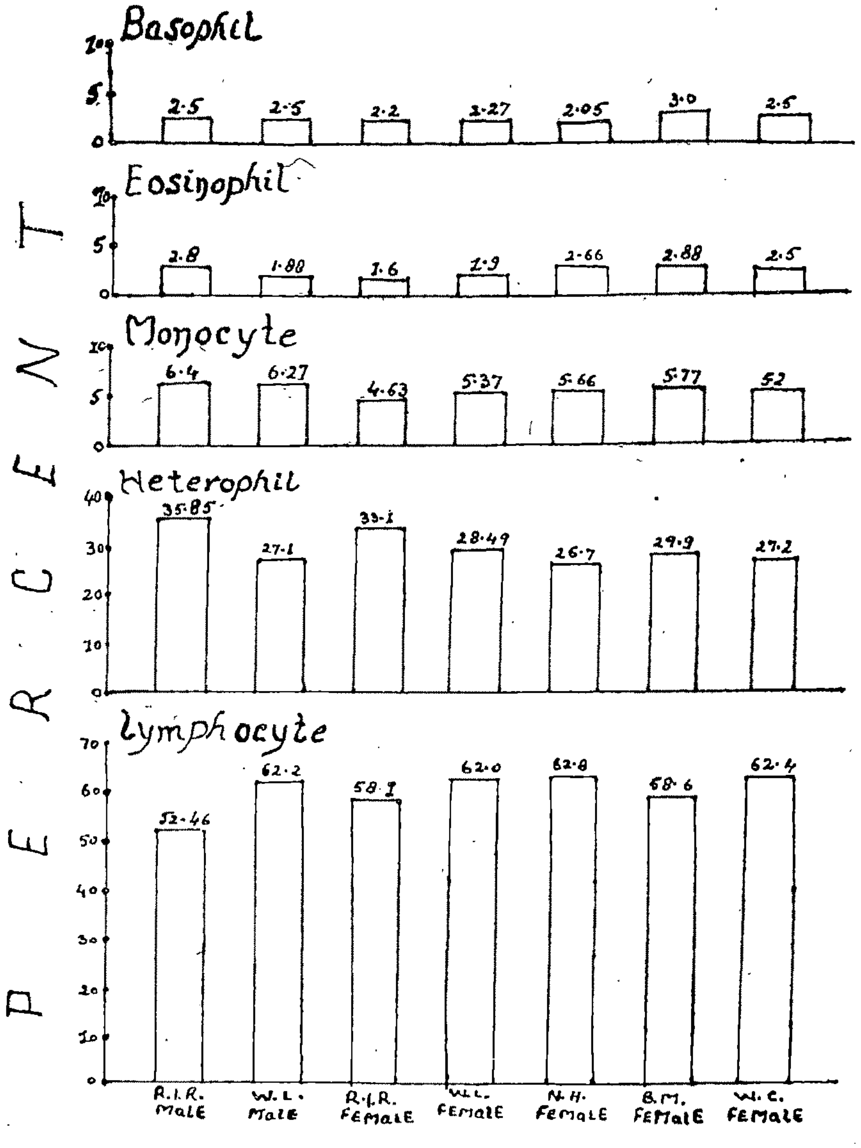
Fig. 1. Mean values of differential leucocyte count of different breeds of poultry in percentage.



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MICROSPOROGENESIS AND THE DEVELOPMENT OF MALE GAMETOPHYTE IN PSIDIUM

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INTRODUCTION

The family Myrtaceae, in spite of its being well represented in the tropics has not been extensively investigated from the morphological point of view as it deserves (Narayanaswami and Roy, 1960; Seth, 1961). The knowledge of microsporogenesis and development of male gametophyte is very important to breeders and so the present study in *Psidium* was conducted at Horticultural Research Institute, Saharanpur.

MATERIAL AND METHODS

Buds and flowers of different stages were fixed in formalin-acetic acid-alcohol from the plants of *P. guajava* L., *P. guineense* Sw. *P. molle* Bertol, *P. chinense* Lodd and *P. cattleianum* f. var. *lucidum* Degener. Dehydration, infiltration and embedding was done as usual (4). Sections cut in order of 8 to 12 microns were stained in safranin—fast green or iron-hematoxylene. Permanent slides for pollen morphological studies were prepared according to technique used by Wodehouse (1935).

Development of male gametophyte was studied from the pollen tubes grown in sugar agar culture media (10% sucrose+0·5% agar). After 8 to 24 hours of dusting the pollen slides were passed in aceto-alcohol (1:3), stained in aceto-carmine and made permanent according to the technique of Bhaduri and Ghosh (1954).

OBSERVATIONS

The cross section of a very young anther is, more or less oval. It shows a mass of homogenous meristematic cells surrounded by an epidermis. Soon it becomes slightly four lobed in the transverse section. At this stage two or three hypodermal cells are discernible in each lobe. The cells which are larger, radially elongated and have conspicuous nuclei are male archesporial cells (Fig. 1). They divide tangentially to form a primary parietal layer towards the outside and a primary sporogenous layer towards the inside. The cells of the former divide by periclinal and anticlinal walls to give rise to four or five concentric layers, composing the anther wall (Figs. 1-4). The primary sporogenous cells undergo further divisions to form a large number of cells, which ultimately function as microspore mother cells.

The epidermis, which is the outermost layer of an anther, undergoes only anticlinal divisions. Its cells become greatly stretched and flatten in a mature anther. Ultimately they lose contact with each other. In a mature anther, are discernible only some withered epidermal cells scattered here and there on the wall (Figs. 7 & 8).

The layer of cells next to epidermis (Figs.8 &10) become radially elongated and develop fibrous bands in each cell. These fibrous bands are most prominent in *P. cattleianum* var. *lucidum* but they are often not so clear in *P. guineense.* There are three more layers of cells inner to the endothesium. Two of these layers form the middle layer. They are thin walled and flatten at the time of microspore mother cells undergoing meiosis (Fig. 5). In most of the anthers these cells are completely crushed before the close of meiosis, but in some they persist, even when the pollen grains are formed and degenerate after that (Fig. 6). The tapetum is the innermost wall layer of the anther. Its cells are full of dense cytoplasm and are uninucleate in early stages (Fig. 2). The same has been reported by Roy (1957) in *Syzygum.* In most of the anthers the tapetal nuclei undergo mitotic division. Large vacuoles appear in their cytoplasm and the nuclei begin to show sign of degeneration (Fig. 6), the tapetal cells are completely absorbed by the time microspores are formed in the anther locules. In a limited number of anthers of *P. chinense*, the tapetal cells become highly vacuolated and acquire bigger size (Fig. 9) but they also degenerate before the bursting of the anthers.

The primary sporogenous cells give rise to the microspore mother cells after undergoing several divisions. The microspore mother cells undergo meiotic mitosis to form four nuclei in a cell (Figs. 11 to 14). The organization of these nuclei into four microspores is simultaneous. The microspore tetrads are generally tetrahedral or isobilateral, but sometimes decussate tetrads are also met with (Figs. 15 to 17).

In *P. guajava*, *P. guineense* and *P. chinense* always four cells are formed after the meiotic mitoses of the microspore mother cells, but in *P. molle* and *P. cattleianum* var. *lucidum*, often five to six cells arise while in the latter only two or three cells may be formed (Figs. 18 to 22). The extra cells, which are in abundance in these two species, are formed of the lagging chromosomes. In *P. cattleianum* var. *lucidum*, of the three cells formed, one is bi-nucleate and the other two uninucleate.

Newly formed microspore has dense cytoplasm with centrally situated nucleus. The microspore grows rapidly in size and the accompanying vacuolation is followed by the displacement of the nucleus from the centre to a place adjacent to the wall. The microspore also soon acquires an exine closely enveloping the intine (Figs. 23 & 24). The pollen grains remain one-celled for a long time and the nucleus only divides three to four days before the dehiscence of the anther. The single nucleus after the mitosis forms a large vegetative and a small generative cell and bicelled pollen are ready to shed (Figs. 25 to 27).

The morphological features of *Psidium* pollen grains are very much like the pollen grains of other members of the Myrtaceae described by Selling (1947), Erdtman (1952) and Pike (1956). The normal sized mature pollen grains of *Psidium* are radio-symmetric but either very small pollen grains or giant pollen grains of *P. cattleianum* var. *lucidum* and *P. molle* are sometimes assymmetric and nonfixiform (Fig. 29). Normal pollen grains are polar and angulaperturate. Pollen grains of *P. guajava, P. guineense* and *P. chinense* have either three or four apertures (Figs. 30 to 35), but in *P. molle* and *P. cattleianum* var *lucidum* even five apertured pollen grains are common (Fig. 28). Normal pollen grains are of medium size (20 to 36 μ) and oblate-subspheroidal to subspheroidal-suboblate (*P. juineense*) in shape.

In *Psidium* species the pollen tube arises in artificial culture within two hours. The vegetative nucleus migrates into the pollen tube after six to eight hours of the sowing and soon reaches the tip while the generative nucleus enters the pollen tube only after 24 hours and both the sperm nuclei migrate to the tip and await its bursting (Fig. 36 to 38).

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EXPLANATION OF FIGURES

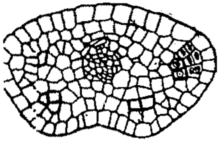
Figs. 1–38 Microsporogenesis and development of male gametophyte.
1–7, 34, 35 to 38 *P. guineense*; 9 *P. chinense*, 10 to 30 *P. cattleianum* var. *lucidum* and 36 *P. molle*.
1. T. S. Young anther showing the male archesporial cells.
2. T. S. Part of anther showing uninucleate tapetum.
3 & 4. T. S. part of anther showing the binucleate tapetum.
Note—Microspore mother cells preparing for reduction division.
5. Part of anther showing degenerated middle layer.
6. T.S. part of anther showing degenerating tapetum and formation of microspore tetrads.
7. T. S. part of anther.

Note—Middle layer and tapetum have degenerated and epidermis is also disintegrating
8 & 10. T.S. part of anther.

Note—fibrous thickening in endothecium.
9. T. S. part of anther showing radial elongation of tapetum cells.
11–14. Different stages of reduction division of microspore mother cells.
15. Isobilateral microspore tetrads.
16–17. Tetrahedral microspore tetrads.
18. Microspore triad.

Note—One of the microspores possesses restitution nucleus, a product of two nuclei
19–20. Microspore dyads.
21–22. More than four microspores formed by a single microspore mother cell.
23–24. Uninucleate pollen grains.
25. Metaphase of the nucleus in an uninucleate pollen grain.
26–27. Bicelled pollen grains.
28–29. Very large pollen grains.

Note—nonfixiform pollen grain in Fig. 29.
30, 32–34. Polar view of pollen grains.
31 & 35. Equatorial view of pollen grains.
36–38. Division of generative nuclei in pollen tubes to form male gametes.
Magnifications. Figs. 1 to 3 and 5 to 10 X 243.
4 and 11 to 36 X 562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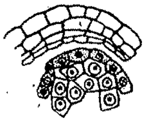
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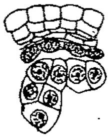
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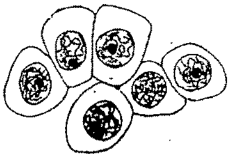
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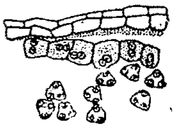
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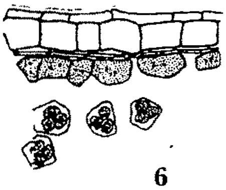
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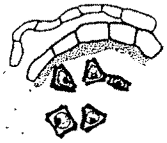
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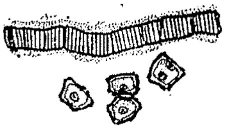
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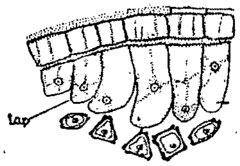

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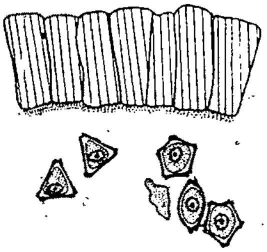
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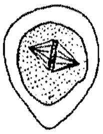
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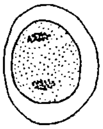
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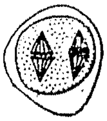
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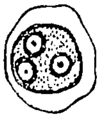
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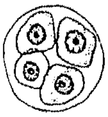
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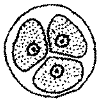
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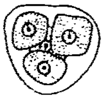
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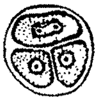
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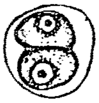
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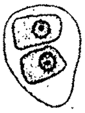
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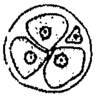
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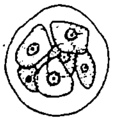
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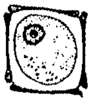
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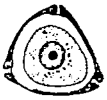
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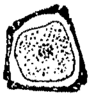
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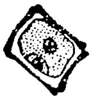
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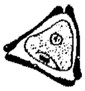
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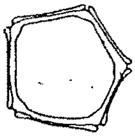
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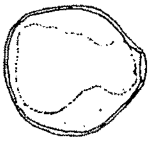
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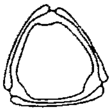
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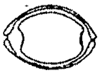
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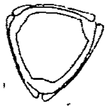
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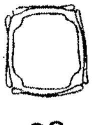
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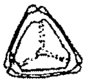
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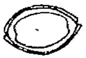
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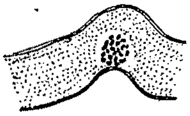
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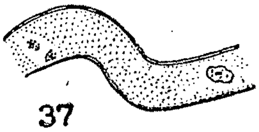
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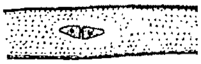
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Agra University Journal of Research (Science),
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Pages 29—34

SOME OBSERVATIONS ON *HIPPOBOSCA LONGIPENNIS* (FABRICIUS) (DIPTERA : HIPPOBOSCIDAE), WITH PARTICULAR REFERENCE TO SEX RATIO

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School of Entomology, St. John's College, Agra (India).

INTRODUCTION

The flies belonging to the Family "Hippoboscidae" Diptera, have evoked much interest among entomologists for a long time. This group is highly adapted for a parasitic mode of life. The external features are modified in accordance with their habits. The life history is also very peculiar. Our knowledge regarding the population and incidence of these flies is very meagre. Hardenberg (1929) studied some aspects of anatomy, embryology and biology of Streblidae and Nycteribiidae; Leuckart (1858) and Pratt (1899) worked on the anatomy and embryology of sheep tick *Melophagus ovinus*, the biology of which has been studied by Swingle (1913), Robert (1925) gave some account on the biology of Hippobosca equina; O'Roke (1930) contributed some details on the biology of Quail-fly *Lynchia hirusta*; Drake and Jones (1930) and Coatrey (1931) has reported the biology of pigeon fly. *Pseudolynchia maura.* Huzimatu (1938) gives a very good account of the biology of Martin fly, *Stenopteryx nopponica.* As much is yet to be known about the distribution, incidence and sex ratio of this group especially of the Indian region, an attempt is made to study the distribution with particular reference to sex ratio of *Hippobosca longipennis,* which is an ectoparasite on dogs.

MATERIAL AND METHODS

The flies were collected daily from the beginning of January to the end of December and weekly record was maintained. The average temperature and humidity in Agra (Longitude 78° and Latitude 27·2° to the north of equator), which is situated 535 feet above sea level was also recorded. Numerous flies of both sexes were collected from domesticated and street dogs. *H. longipennis* commonly known as the "Louse fly" or the "Flat fly" is quite abundant on dogs. Street dogs are more parasitized with flies than the domesticated ones and apparently the flies seem to show a special liking for brown dogs. The adult flies were first fixed in Bouin's fluid or Carnoy's fluid and then preserved in 70% alcohol.

THE HOST-PARASITE RELATIONSHIP

It is interesting to record in this connection that these flat flies show a preference to dogs only. They are more abundant on the ventral side of the host specially at the neck region and in the arm pits. They are voracious blood sucking parasites and when separated from the host they do not survive for more than a few minutes.

Being a pupipera the fly is known for its high fecundity. The female genital chamber always carries the developing larva.

THE INCIDENCE

From the table given before, the relation between the temperature and humidity with the number of flies collected is quite significant. From the given graph it is observed that the maximum number of flies appear in June when the temperature is high and the humidity comparatively low, although the maximum temperature was recorded in May when the humidity was very low. It indicates that with the decrease of temperature and increase in humidity there is accelerated rate of emergence of fly and consequent increase in number in June. It is also observed that with the fall of temperature and comparative increase of humidity the number steadily decreases and no fly is collected in November, December and January when the temperature is lowest.

THE SEX RATIO

More street dogs when examined were infected with these flies. The maximum number of flies collected from a single host was 22 while the minimum was one. Out of the total number of 224 flies collected, 129 were males and 95 females. Hardenberg (1929) has summarized the observations on some flies belonging to the family Hippoboscidae. In *H. rufipes*, he reported the sex ratio as 1:1. In the case of the sheep tick, out of 840 flies collected by him the females were 501 and males 339. In case of *Stenopteryx hirundiris* reported by him the number of female flies was also high and for this he gave two explanations, firstly the life of the male is shorter than that of the female and secondly the males are more active and are capable of escaping from the nest. The same type of sex ration is reported by Huzimatu (1938) in *Stenopteryx nipponica*. But in case of *Hippobosca longipennis* the males are more than the females; the ratio being 30:27.

SUMMARY

Maximum number of flies appear when the temperature is high and the humidity moderate. Flies disappear when the temperature is lowest. The sex ratio of *Hippobosca longipennis* as stated above, shows that the number of male flies is higher than the female, unlike other flies belonging to the same family where the sex ratio is just the reverse.

ACKNOWLEDGEMENTS

I am very grateful to Dr. V. P. George, Associate Professor of Entomology, St. John's College, Agra for his constant encouragement and guidance during the survey. My thanks are due to Dr. T. Singh, Professor of Entomology, St. John's College, Agra and to Sri P. T. Chandi, the former Principal, St. John's College, Agra, for their manifold help.

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TABLE 1

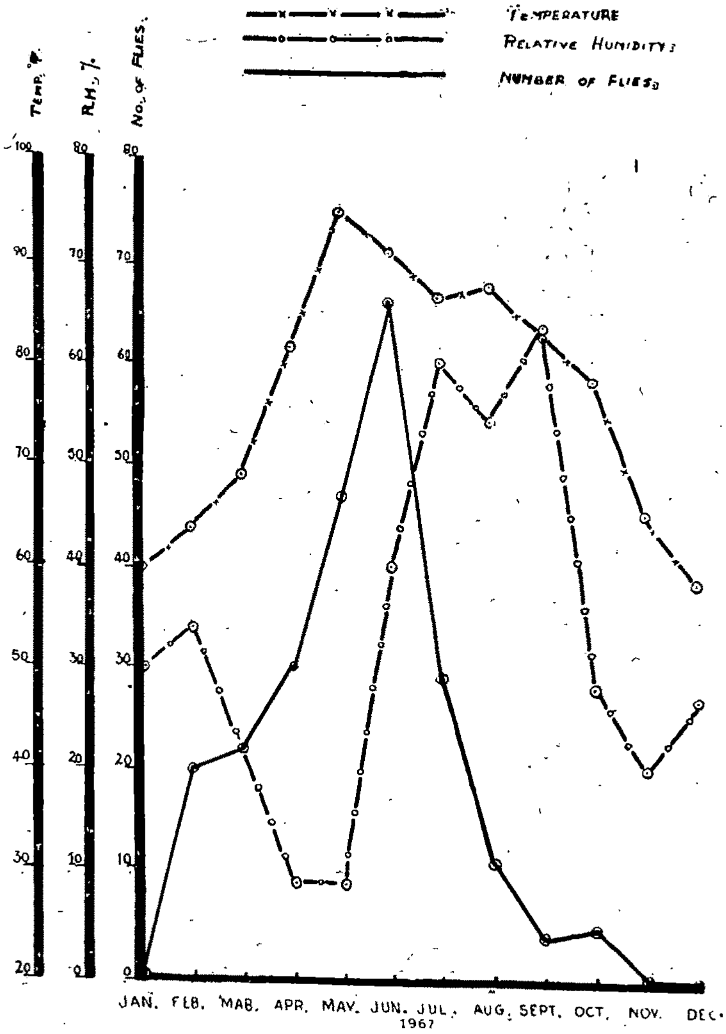
Table showing the details of the number of H. capensis collected.

Month & Year	Weeks	No. of flies collected	Total monthly	No. of male collected	Total monthly	No. of female collected	Total monthly	male or female type of host	R.H. average	Temperature in °F
Jan., 1967	I	...	...	...	...	...	...	...	30%	59·6
	II	...	...	...	...	...	...	...		
	III	...	...	...	...	...	...	...		
	IV	...	...	...	...	...	...	...		
Feb., 1967	I	6	20	4	11	2	9	Street male	34%	63·8
	II	4		3		1		Street female		
	III	7		3		4		Dom. female		
	IV	3		1		2		Street female		
March, 1967	I	5	22	4	15	1	7	Street female	22%	69·2
	II	7		5		2		Dom. female		
	III	2		2		...		Dom. female		
	IV	8		4		4		Street female		
April, 1967	I	8	30	5	18	3	12	Street female	9%	81·8
	II	7		4		3		Street male		
	III	15		9		6		Street male		
	IV	...		...		...		...		
May, 1967	I	10	47	7	25	3	22	Street male	9%	94·7
	II	14		5		9		Street male		
	III	7		4		3		Street female		
	IV	16		9		7		Street female		
June, 1967	I	17	66	8	35	9	31	Street male	40%	90·8
	II	9		5		4		Dom. male		
	III	18		9		9		Street male		
	IV	22		13		9		Street male		

TABLE 1—(*Contd.*)

Table showing the details of the number of H. capensis collected.

Month & Year	Weeks	No. of flies collected	Total monthly	No. of male collected	Total monthly	No. of female collected	Total monthly	male or female type of host	R. H. average	Tempera-ture in °F.
July, 1967	I	19	29	9	14	10	15	Street female	60%	86·2
	II	6		3		3		Dom. male		
	III	4		2		2		Street male		
	IV	...		...		...		...		
Aug., 1967	I	5	11	4	6	1	5	Street female	54%	87·2
	II	1		...		1		Street female		
	III	5		2		3		Street female		
	IV	...		...		...		...		
Sept., 1967	I	1	4	1	2	...	2	Street male	63%	82·6
	II	2		1		1		Street male		
	III	1		...		1		Street male		
	IV	...		...		...		...		
Oct., 1967	I	3	5	2	3	1	2	Dom. male	28%	78·0
	II	2		1		1		Street male		
	III	...		...		...		...		
	IV	...		...		...		...		
Nov., 1967	I	...	...	...	...	...	...	...	20%	65·0
	II	...		...		...		...		
	III	...		...		...		...		
	IV	...		...		...		...		
Dec., 1967	I	...	...	...	...	...	...	...	27%	58·4
	II	...		...		...		...		
	III	...		...		...		...		
	IV	...		...		...		...		
Total		224		129		95				



GRAPH SHOWING RELATION BETWEEN TEMPERATURE AND HUMIDITY WITH THE NUMBER OF FLIES

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Pages 35-50

STUDIES ON THE VARIATION OF THE STABILITY OF SOME ANISOMETRIC PARTICLE SOLS WITH THE CONCENTRATION OF COAGULATING ELECTROLYTE

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SUMMARY

The variation of the stability of ferric tellurate, chromium tellurate, stannic hydroxide and ferric hydroxide sols (anisometric particle sols) has been studied at different periods of dialysis, ageing and at different dilutions and also in the presence of various non-electrolytes by plotting log t as a function of $\sqrt{C_e}$ (C_e is the molar concentration of electrolyte). It is interesting to note that the inference, drawn from the values of flocculation concentration (determined from log t vs. $\sqrt{C_e}$ curves), about the influence of dialysis, ageing, dilution and of non-electrolytes on the stability of the above mentioned sols is the same as that obtained on the basis of $(a+m)$ values of Bhattacharya's equation[3].

INTRODUCTION

The stability of lyophobic sols is generally measured by the function of log W where W is the rate of slow coagulation, relative to that for rapid coagulation (for which $W=1$). The stability falls rapidly on addition of electrolytes (at concentration C_e) to a maximum at the coagulation value, $C_e=\bar{C}_e$ where C_e is the molecular concentration of the electrolyte.

On addition of electrolytes that coagulate by compression of the electrical double layer, log W for spherical particle sols decreases continuously with increasing C_e values, according to the following relation derived from the Verwey-Overbeek theory[7],[8]:

$$\log W=C_1\gamma^2(\log C_2\gamma^4-\log C_e) \quad \ldots(1)$$

C_1 and C_2 are constants.

γ is a function of Ψ_s, the surface potential

$$\gamma=\frac{[\mathrm{Exp}\,(Z/2)-1]}{[\mathrm{Exp}\,(Z/2)+1]} \quad \ldots(2)$$

where $$Z=\frac{V\,e\Psi_s}{kT}$$

V is the valency of the gegen—ion,
e, k are the physical constants,
T is the sol temperature.

For anisometric particle sols, log W decreases according to the relation[4],

$$\log W = C_3\gamma^4 - C_4\gamma^2\sqrt{C_e} \qquad ..(3)$$

C_3, C_4 are constants.

γ varies with Ψ_s as in equation (2).

According to Packter[5]

$$\log W = \log t/\bar{t}$$

where $\bar{t}$ is the time of rapid coagulation, at $C_e = \bar{C}_e$ (the coagulation value).

Since for a particular sol and a particular coagulating electrolyte $\bar{t}$ will be constant and hence for a sol coagulated by different concentrations of the same electrolyte

$$\log W \,\alpha\, \log t \qquad ..(4)$$

(Packter, loc. cit.)

$$\text{or} \quad \log W = K \log t \qquad ..(5)$$

(K is a constant)

So the variation of log t with concentration of coagulating electrolyte may give an idea of the variation of the sol stability. With this aim in view, it was thought worthwhile to study the variation of the stability of ferric tellurate, chromium tellurate, stannic hydroxide and ferric hydroxide sols (anisometric particle sols), at different periods of dialysis, ageing and at different dilutions and also in the presence of various non-electrolytes by plotting log t as a function of $\sqrt{C_e}$. In previous publications[9-13] we have studied the stability of a number of lyophobic sols at various stages of dialysis, ageing, dilution and in the presence of non-electrolytes in the light of Bhattacharya's equation[3], $C = a + \dfrac{m.\ 1/t}{n + 1/t}$. The present studies give a striking evidence in support of the applicability of this equation in as much as that the values of flocculation concentration obtained from log t vs. $\sqrt{C_e}$ plots for rapid coagulation and that of $(a+m)$, calculated on the basis of this equation are almost identical.

EXPERIMENTAL

(*i*) *Preparation of the sols*

Ferric and chromium tellurate sols were prepared by the method reported in our recent publication[14] and ferric hydroxide and stannic hydroxide sols were prepared by the method reported in our earlier publications (loc. cit.). Different samples of sols were prepared to study the variation of their stability at different periods of dialysis, ageing and at different dilutions and also in the presence of non-electrolytes.

(*ii*) *Determination of the time of coagulation*

The time of coagulation of the sols, using different concentrations of the uni-, bi- and tri-valent electrolytes was determined by Light Extinction Method[6], using a "Gallenkamp" Photoelectric Colorimeter.

(*iii*) *Determination of flocculation concentration*

The flocculation concentrations of different electrolytes for the sols were calculated[15,16] by extrapolating the linear portion of the plots between log t and $\sqrt{C_e}$ (Figs. 1—9) to $\sqrt{C_e}$ axis where log $t=0$ (i.e., log $W=0$ since log $W=K'$ log t) assuming the validity of the equation:

$$\log W = C_3\gamma^4 - C_4\gamma^2\sqrt{C_e}.$$

(iv) The value of $(a+m)$ was obtained by determining the values of a and m graphically[1].

The values of flocculation concentration obtained from log t vs. $\sqrt{C_e}$ plots for rapid coagulation and also that of $(a+m)$ calculated on the basis of the equation, $C=a+\frac{m.1/t}{n+1/t}$ have been recorded in the following tables:

TABLE 1

Effect of dialysis

Period of dialysis (days)	(a+m) mM/l			Flocculation concentration from log t vs. $\sqrt{C_e}$ plots mM/l		
	KCl	K_2SO_4	$K_3Fe(CN)$	KCl	K_2SO_4	$K_3Fe(CN)_6$
			Ferric tellurate sol			
2	2228·60	3·1524	1·6250	2260·16	3·1329	1·6129
3	926·31	2·8100	1·5143	961·00	2·8220	1·5376
4	335·30	2·2000	1·4140	361·00	2·1904	1·4400
5	175·00	2·1000	1·2143	179·56	2·0730	1·2544
6	121·43	1·9000	1·0400	121·00	1·9044	1·1881
7	98·82	1·6500	0·9260	92·16	1·7689	1·0400
8	57·80	1·6000	0·8500	57·76	1·7424	0·9216
9	40·08	1·3700	0·8000	40·96	1·4400	0·8649
			Chromium tellurate sol			
4	...	2·325	1·490	...	2·3409	1·5376
7	3700·00	1·455	0·900	3745·44	1·5876	0·9604
10	150·00	1·266	0·657	153·76	1·4160	0·7569
13	52·77	1·055	0·533	51·84	1·2100	0·6184
16	21·75	0·830	0·445	23·04	0·8649	0·5329
19	13·09	0·554	0·2881	12·96	0·6084	0·3600

TABLE 2

Effect of ageing

Period of ageing (days)	(a+m) mM/l		Flocculation concentration from log t vs. $\sqrt{C_e}$ plots mM/l	
	KCl	NaCl	KCl	NaCl
	Stannic Hydroxide sol			
0	92·26	60·83	94·09	64·00
15	88·60	60·00	88·36	62·41
30	80·00	57·72	86·49	59·24
60	76·60	55·64	82·81	56·25
90	70·60	47·50	77·44	51·84
105	66·40	43·26	72·25	47·61
	Ferric Hydroxide Sol			
7	171·10	168·10	176·89	179·56
21	84·16	75·00	81·00	81·00
35	53·46	52·26	57·76	54·76

TABLE 3

Effect of dilution

	(a+m) mM/l			Flocculation concentration from log t vs. $\sqrt{C_e}$ plots mM/l		
	KCl	K_2SO_4	$K_3Fe(CN)_6$	KCl	K_2SO_4	$K_3Fe(CN)_6$
	Ferric Tellurate Sol					
Sol A	123·80	1·800	1·030	127·69	1·9600	1·0000
,, 2A/3	123·82	1·750	0·850	127·69	1·8496	0·9216
,, A/2	131·66	1·509	0·757	132·25	1·6384	0·8100
	Chromium Tellurate Sol					
Sol A	138·82	1·166	0·583	144·00	1·2321	0·5776
,, 3A/4	162·50	1·045	0·450	174·24	1·0816	0·4900
,, A/2	198·82	0·788	0·433	201·64	0·8281	0·4356

TABLE 4

Effect of non-electrolytes

	(a+m) mM/l			Flocculation concentration from log t vs. $\sqrt{C_e}$ plots. mM/l		
	KCl	K_2SO_4	$K_3Fe(CN)_6$	KCl	K_2SO_4	$K_3Fe(CN)_6$
			Ferric Tellurate Sol			
Sol (without non-electrolyte)	105·45	2·3752	1·2072	112·36	2·4025	1·2100
Methanol (1·5 ml)	63·81	2·1310	1·0154	67·24	2·2800	1·0000
Ethanol (1·5 ml)	62·22	1·9500	0·9200	54·76	1·9600	0·9025
Isopropanol(1·5 ml)	41·74	1·9225	0·8252	44·89	1·9044	0·8281
Acetone (1·5 ml)	36·66	1·7424	0·8425	39·69	1·7424	0·8649
Formamide(1·0 ml)	20·65	1·1564	0·4752	19·36	1·1664	0·4900
Dioxane (1·5 ml)	41·25	1·7500	0·8725	43·56	1·7161	0·9600
Urea 5 M(1·5 ml)	115·00	2·5450	1·3500	129·96	2·5281	1·3450
Glycerol 50% (1·5ml)	130·00	2·7250	1·4750	141·61	2·7220	1·5129
			Chromium Tellurate Sol			
Sol (without non-electrolyte)	150·60	1·4952	0·8350	153·76	1·5129	0·8464
Ethanol (1·5 ml)	62·03	1·1500	0·6785	60·84	1·1664	0·6724
Acetone (1·5 ml)	45·00	1·0820	0·6000	46·24	1·0816	0·6084
Formamide (1·5 ml)	30·64	0·5345	0·3250	33·64	0·5476	0·3136
Dioxane (1·5 ml).	900·00	1·4380	0·8150	900·00	1·3924	0·7921
Urea 5 M(1·5 ml)	186·66	1·5770	0·9052	184·96	1·5625	0·9125
Glycerol 50% (1·5 ml)	227·00	1·6035	0·9150	231·04	1·6129	0·8836

DISCUSSION

Figures 1 to 9 have been drawn for ferric tellurate and stannic hydroxide sols. Similar figures were obtained with other sols. From these figures it is evident that log *t* decreases steadily with increasing concentration of electrolyte indicating that the stability of lyophobic sols decreases steadily with the concentration of electrolyte, until the curves which are of the form predicted theoretically by Packter (loc. cit.) become parallel to the $\sqrt{C_e}$ axis at a certain concentration(Figs. 1—9). The change in slope seems to correspond to the transition from slow coagulation to rapid coagulation. The flocculation concentrations, for different electrolytes determined for rapid coagulation, are in the decreasing order to valency of the precipitating ion as demanded by Schulze-Hardy valency rule.

According to Bhattacharya and coworkers[2] if $1/t$ is made large as compared to 'n', the equation $C=a+\frac{m.1/t}{n+1/t}$ takes up the form, $C=a+m$. This means that 'm' is the excess of the electrolyte that should be added above the critical stability concentration 'a', in order to cause the immediate coagulation of the sol. In other words $(a+m)$ is the concentration which should be added to cause the rapid coagulation.

The inference drawn from the values of flocculation concentration, about the influence of dialysis, ageing, dilution and of non-electrolytes on the stability of ferric tellurate, chromium tellurate stannic hydroxide and ferric hydroxide sols, is the same as has been discussed on the basis of $(a+m)$ values in our previous publications (loc. cit.).

On going through tables 1—4, it is interesting to note that the values of flocculation concentration (determined from log t vs. $\sqrt{C_e}$ curves) and of $(a+m)$ (calculated on the basis of the equation $C=a+\frac{m.1/t}{n+1/t}$) are in close agreement to each other. As discussed above, in the equation $C=a+\frac{m.1/t}{n+1/t}$, $(a+m)$ is the concentration of the electrolyte required for the rapid coagulation of sol. Hence the value of coagulation concentration (flocculation value) for the rapid coagulation of sols can be calculated approximately by the use of the equation,

$$C=a+\frac{m.1/t}{n+1/t}.$$

Since the values of the concentration of electrolyte, required for the rapid coagulation, determined separately on the basis of the equations: $C=a+\frac{m.1/t}{n+1/t}$ and $\log W=C_3\gamma^4-C_4\gamma^2\sqrt{C_e}$, are approximately the same, it may be inferred that the fundamental approach of both the equations is the same.

ACKNOWLEDGEMENTS

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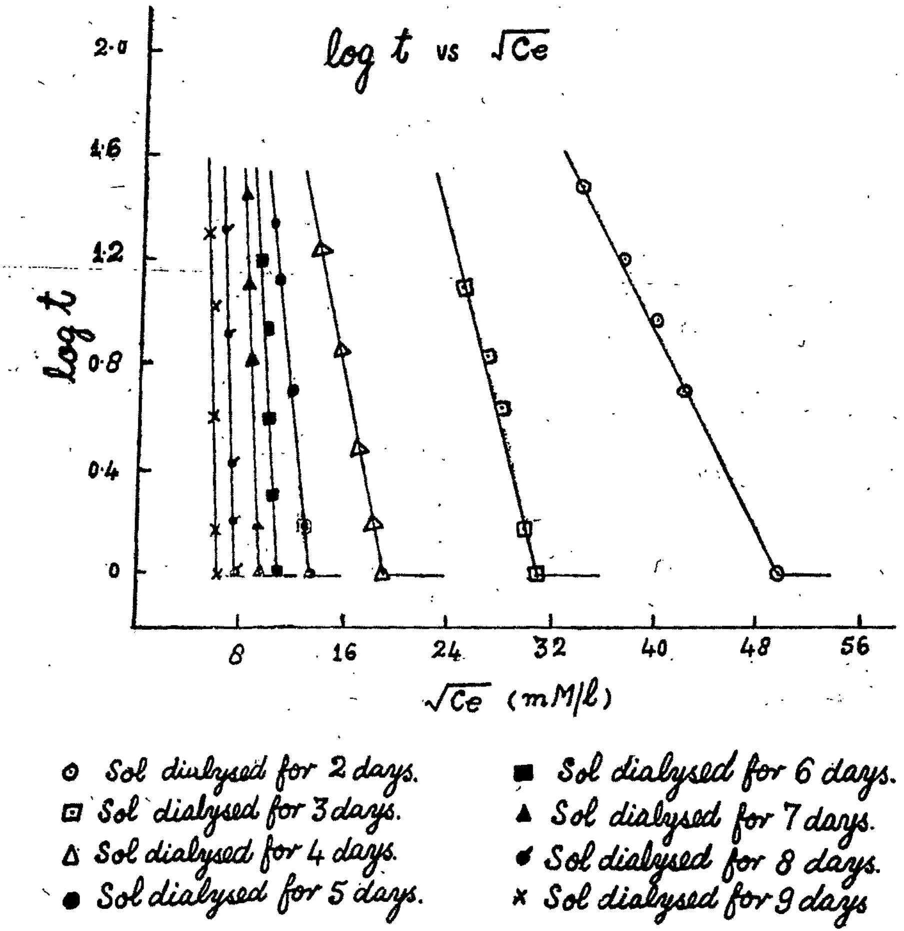

Fig. 1

Coagulation of Ferric Tellurate Sol with KCl at different periods of Dialysis.

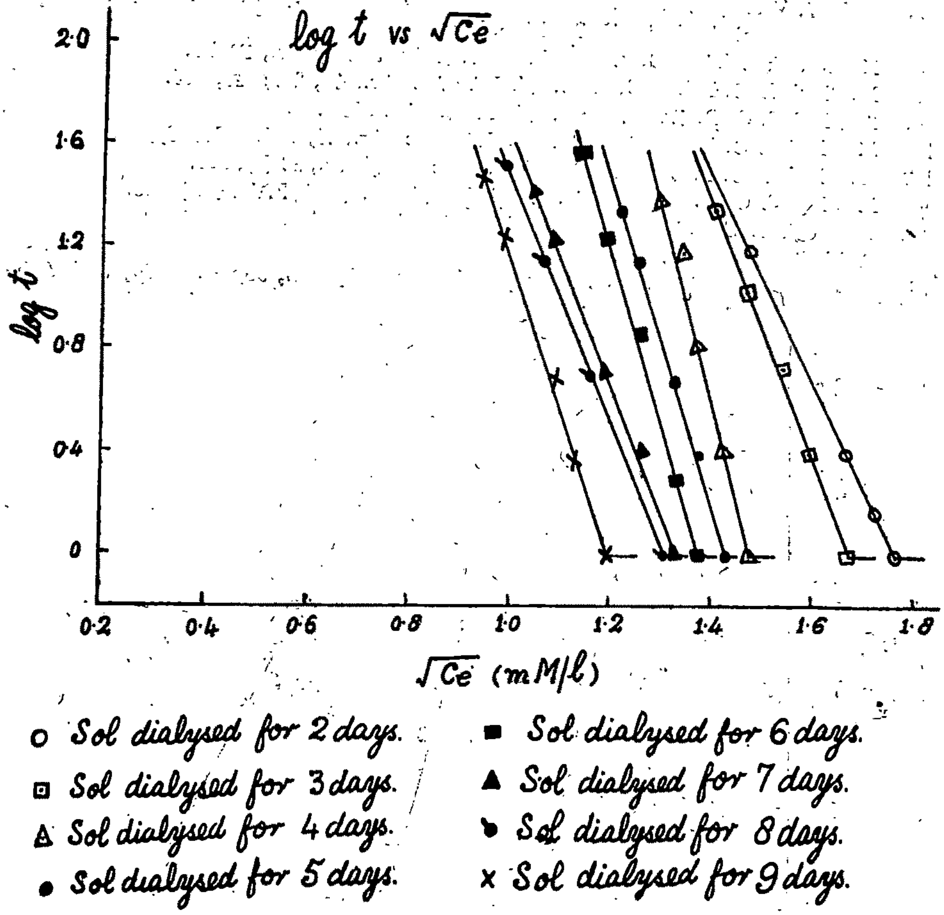

FIG. 2

Coagulation of Ferric Tellurate Sol with K_2SO_4 at different periods of Dialysis.

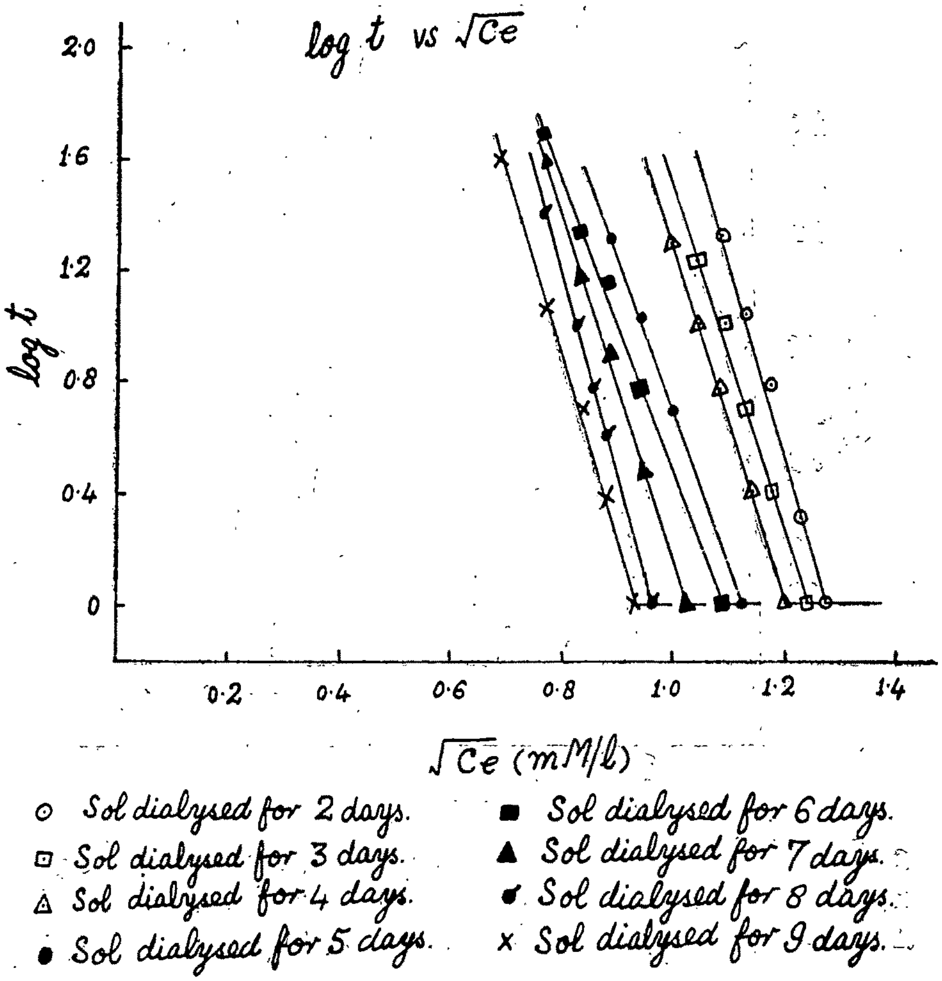

FIG. 3

Coagulation of Ferric Tellurate Sol with $K_3 Fe (CN)_6$ at different periods of Dialysis.

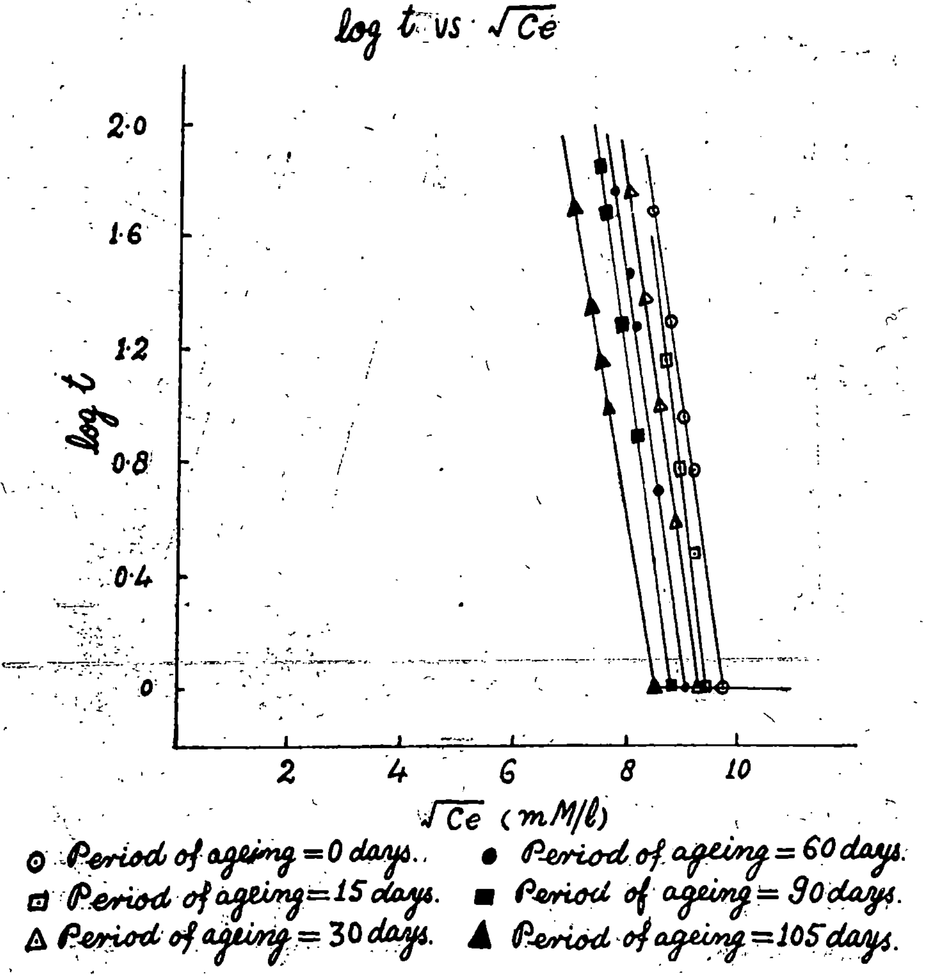

FIG. 4

Coagulation of Stannic Hydroxide Sol with KCl at different periods of Ageing.

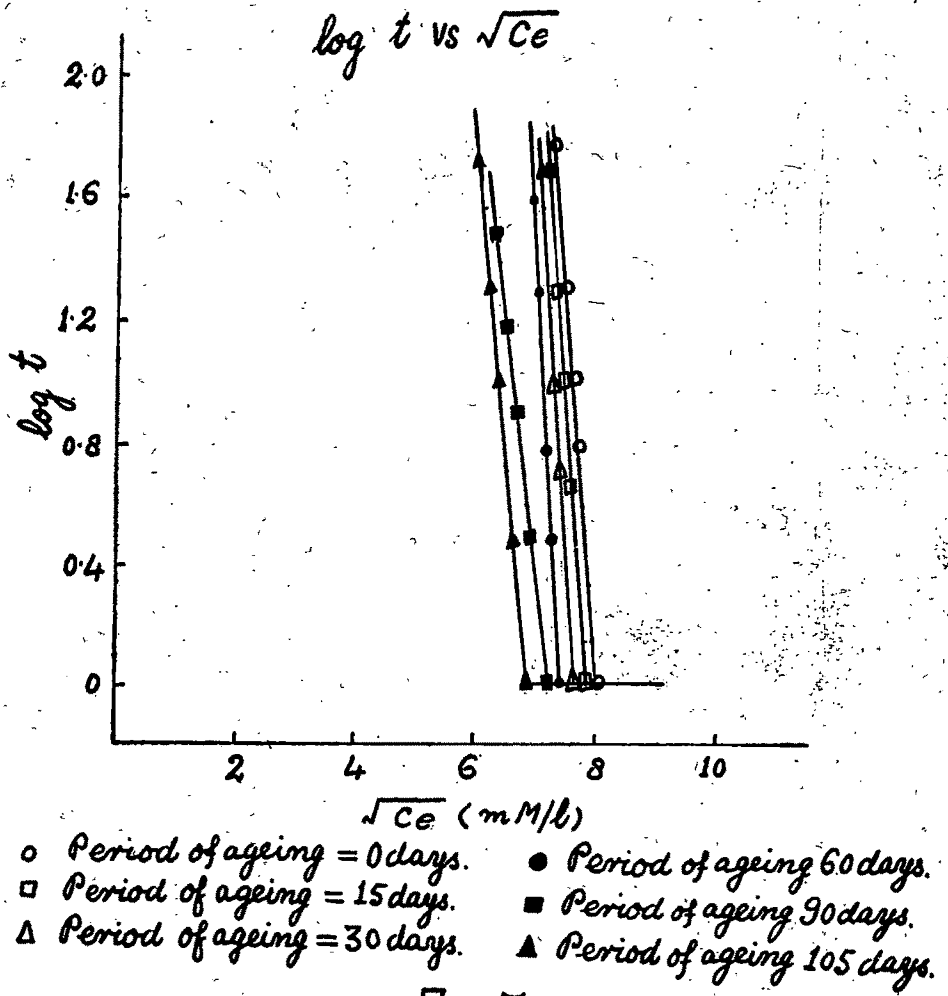

FIG. 5

Coagulation of Stannic Hydroxide Sol with NaCl at different periods of Ageing.

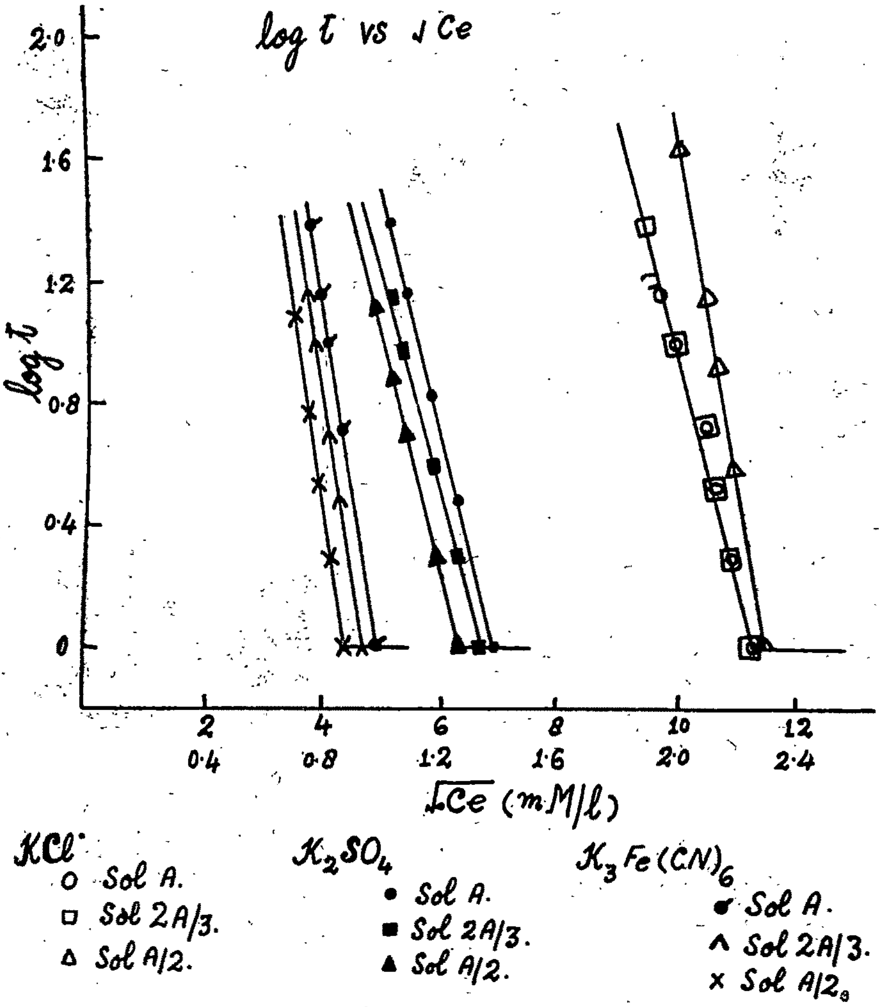

FIG. 6

Coagulation of Ferric Tellurate Sol with KCl, K_2SO_4 and $K_3Fe(CN)_6$ at different Dilutions.

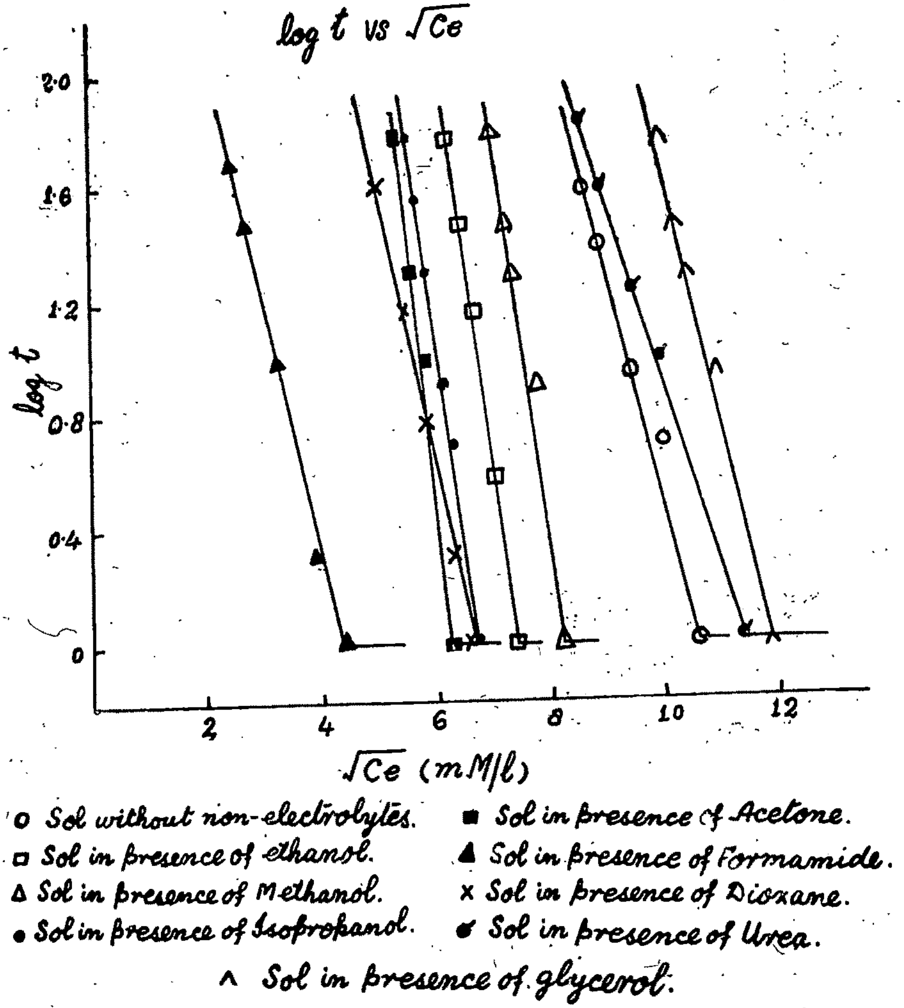

FIG. 7

Coagulation of Ferric Tellurate Sol (In presence of non-electrolytes) with KCl.

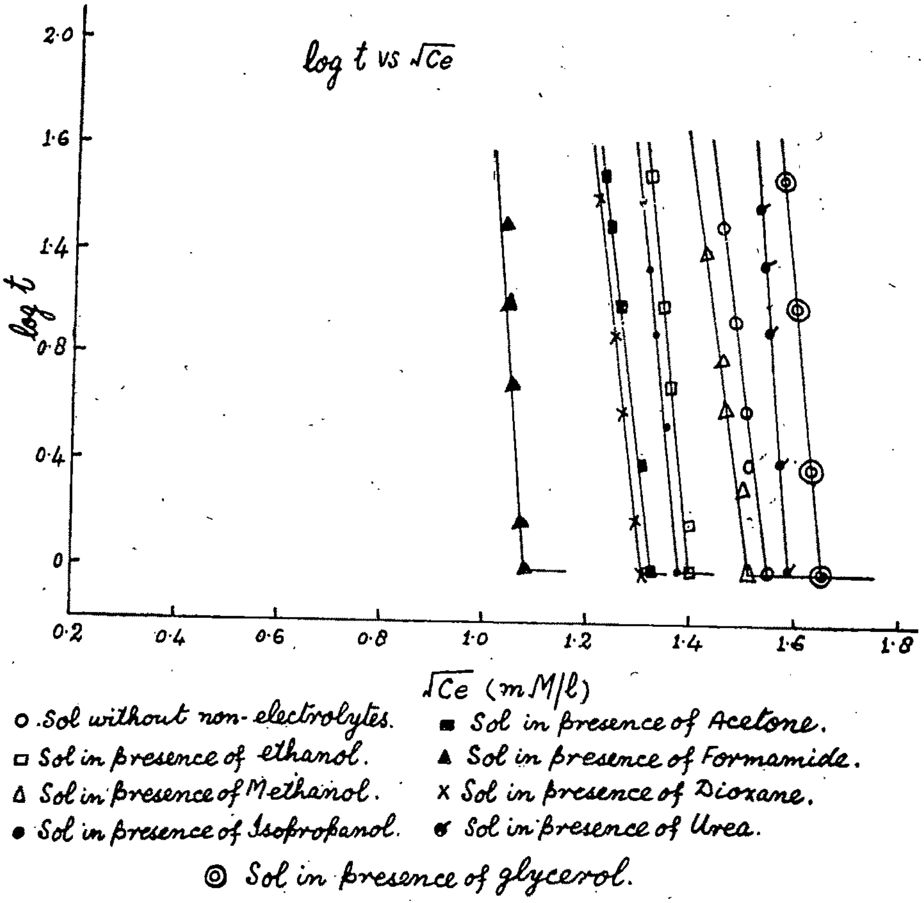

FIG. 8

Coagulation of Ferric Tellurate Sol (In presence of non-electrolytes) with K_2SO_4

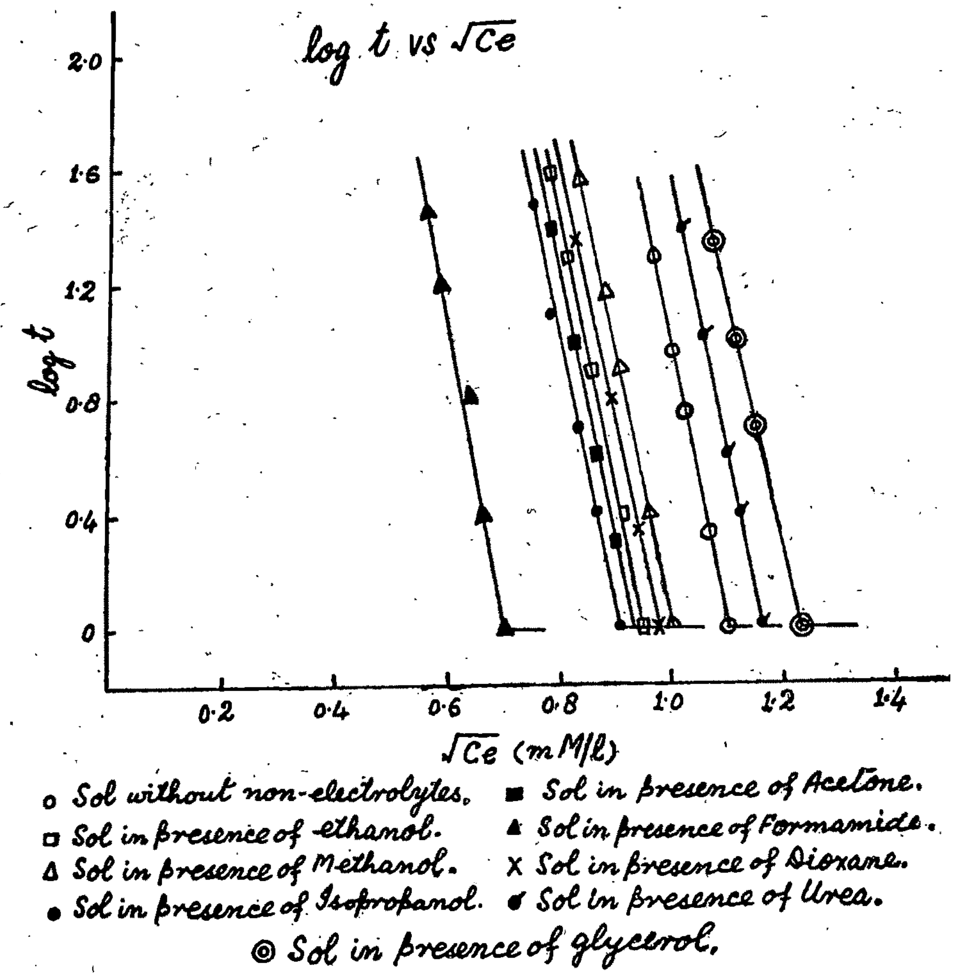

FIG. 9

Coagulation of Ferric Tellurate Sol (In presence of non-electrolytes) with $K_3Fe(CN)_6$

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STUDIES ON MILK FAT GLOBULES*

VII—EFFECT OF LEVELS OF NUTRITION ON THE SIZE AND NUMBER OF FAT GLOBULES

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The effect of different feeds and fodders on the quality and quantity of milk in cows is well known. Among milch animals in India, goat occupies an important place from both dairy as well as economic point of view. It is considered to be the Poor man's cow, yet it has been more or less neglected. Goats are generally fed on Pasture and are seldom stall fed.

Very little data is available regarding the effect of feeds on the size and number of fat globules in milk, but no systematic work in this line has been attempted.

Practically the only information available on the effect of nutrition on the size and number of fat globules in milk by Hunziker et al (1912) who have reported that changing the animals (cows) from succulent to dry feeds resulted in the formation of smaller fat globules, while change from dry feed to pasture of feeding on a ration high in oil content tended to produce larger fat globules.

The authors got an opportunity to study the effect of feeding goats at different levels of protein and energy (Low, medium and high) on the size and number of fat globules in milk. The results obtained have been presented in these pages.

METHODS AND MATERIALS

The study was done on two breeds of goats i. e., Jamunapari, and Barbari maintained under P. L.—480 Goat Scheme.

Goats were fed at three levels of protein (Low, Medium, and High) and three levels of energy (Low, Medium, and High) thus involving, in all, nine diff-

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erent combinations (groups). From amongst the animals in each group—eight animals, 4 of each breed, were selected at random. The levels of protein and energy were adjusted at 75%, 100% and 125% of Morrison standards. The adjustments of D. C. P. was done by suitably adjusting the proportions of concentrates. Lin-seed and Barley and T. D.N. level was adjusted by suitable amount of wheat Bhusa or gram husk.

Each animal also received, in addition, 250 gms. of green Lobia to supply carotene. Mineral Mixture and Sodium Chloride also was given as usual.

The sampling of milk and preparation of slides was the same as employed earlier (Maheshwari, Ogra and Rao, 1969). Samples were collected from each animal through out the experimental period.

Results and Discussion

Size of Fat Globules—The results obtained in the present investigation have been summarised in the following table:—

Table 1

Showing the average and range values of fat globule size obtained under different levels of nutrition

(Size in Microns)

Group No.	Level of Nutrition	Jamunapari Goat			Barbari Goat		
		No. of samples	Average	Range	No. of samples	Average	Range
1.	HP+HE**	16	2·43	(0·62—7·80)	16	1·83	(0·62—6·24)
2.	HP+ME	16	2·15	(0·31—7·80)	16	2·73	(0·62—9·36)
3.	HP+LE	16	2·87	(0·62—9·36)	16	2·18	(0·31—6·24)
4.	MP+HE	16	2·33	(0·62—6·24)	16	2·00	(0·31—7·80)
5.	MP+ME	16	2·89	(0·62—6·24)	16	2·08	(0·62—9·36)
6.	MP+LE	16	2·82	(0·62—7·80)	16	1·90	(0·31—9·36)
7.	LP+HE	16	2·55	(0·62—6·24)	16	2·08	(0·62—7·80)
8.	LP+ME	16	3·42	(0·62—9·36)	16	2·11	(0·62—9·36)
9.	LP+LE	16	2·64	(0·62—6·24)	16	2·67	(0·62—9·36)

** Explanation of Symbols:
H. M. L. indicate High, Medium, and Low levels respectively
P and E stand for Protein and Energy

Statistical analysis of data (on the Mean values of the 4 replications) was also done and the results obtained have been summarised in the following table:—

TABLE 2

Showing statistical analysis of the effect of different nutritional levels on the size of fat globules

Sl. No.	Particulars	D F.	S.S.	M.S.S.	'F' Value
1.	Between breeds	1	4·60	4·60	23·00**
2.	Between levels of protein	2	0·88	0·44	2·2
3.	Between levels of energy	2	1·86	0·93	4·65*
4.	Protein×Energy	4	0·19	0·04	0·20
5.	Breed×Protein	2	0·66	0·33	1·65
6.	Breed×Energy	2	0·02	0·01	0·005
7.	B×P×E	4	3·56	0·89	4·45*
8.	Error	54	10·86	0·20	...

* Significant at 5% level.
** Significant at 1% level.

TABLE 2 (*a*)

Showing significant differences

Particular	Energy			Breed	
	HE	ME	LE	Jamunapari	Barbari
Mean size	2·2046	2·6141	2·5164	2·6785	2·2115
Critical Difference	...	0·256	...	0·210	...

The results of statistical analysis are self explanatory.

Animals in high energy group produced fat globules of smaller size than those in low and medium energy groups, though, no difference could be noted between the latter two groups.

Animals in the medium energy group produced milk with slightly numerically bigger fat globules than those in low energy groups. Both the breeds responded in the same tone but milk of Jamunapari goats showed bigger sized fat globules than that of Barbari goats at all the different levels of protein and energy. The better response of Jamunapari breed to the different levels of nutrition may probably be due to physiological differences between the two breeds. This seems to be further confirmed by the fact that these levels of nutrition had no significant difference between the number fat of globules. However, a numerical difference existed in the average values observed.

No published data are available to confirm or otherwise the present findings.

Number of fat globules

TABLE 3

Showing the average and range of the number of fat globules obtained under different levels of nutrition.

(In hundred thousands)

Group No.	Level of Nutrition	Jamunapari Goat			Barbari Goat		
		No. of samples	Average	Range	No. of samples	Average	Range
1.	HP+HE	16	46·55	(27·15—73·25)	16	38·27	(21·17—59·71)
2.	HP+ME	16	39·14	(19·54—55·19)	16	49·55	(56·99—64·11)
3.	MP+LE	16	34·65	(29·85—41·53)	16	44·14	(40·71—59·70)
4.	MP+HE	16	39·62	(25·22—88·64)	16	41·11	(24·13—62·71)
5.	MP+ME	16	41·68	(14·75—56·11)	16	38·20	(43·54—52·11)
6.	MP+LE	16	40·11	(54·31—61·91)	16	43·86	(29·85—59·53)
7.	LP+HE	16	36·55	(14·22—76·22)	16	38·41	(21·82—50·51)
8.	LP+ME	16	36·24	(16·31—50·51)	16	38·34	(23·44—61·97)
9.	LP+LE	16	42·52	(20·13—56·55)	16	45·71	(31·52—73·32)

TABLE 4

Statistical analysis showing the effect of different nutritional levels on the number of fat globules

S. No.	Particulars	D.F.	S.S.	M.S.S.	'F' Value
1.	Between breeds	1	0·02	0·020	0·01
2.	Between levels of protein	2	0·01	0·005	0·00
3.	Between levels of Energy	2	1·49	0·745	0·40
4.	Protein×Energy	4	2·00	0·500	0·27
5.	Breed×levels of protein	2	0·42	0·210	0·11
6.	Breed×Energy	2	1·69	0·845	0·46
7.	B×P×E	4	4·46	1·115	0·61
8.	Error	54	98·18	1·818	...

No Statistically significant difference was noticeable between the two breeds for levels of protein and energy in the number of fat globules per ml. of milk. This would mean that the different nutritional levels have no effect on the number of fat globules.

However, a small numerical difference existed in the number of fat globules between the different levels of nutrition, but the response of the two breeds in this respect does not show any definite trend.

Since there is no published data, the above findings can only be confirmed by further work along these lines.

SUMMARY

The effect of different nutritional levels was studied on the size and number of fat globules in milk of goats (maintained under PL—480 Goat Scheme).

1. Different energy and protein levels had no significant effect on the number of fat globules.
2. The size of fat globules was significantly affected by levels of energy. The significance was more pronounced in the groups of Medium and Low energy levels.
3. In general and particularly in respect of size of fat globules, Jamunapari showed a better response to the different nutritional levels than Barbari.
4. Levels of protein had no effect on the size and number of fat globules.

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ABELIAN AND TAUBERIAN THEOREMS FOR A GENERALISED LAPLACE INTEGRAL

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Introduction

The object of this paper is to give two Abelian theorems and one Tauberian theorem for the generalised Laplace-Steiltjes transform

$$f(s)=2^{-\nu/2}\int_0^{\infty}(st)^{\lambda}\,e^{-\frac{1}{2}st}.\,D\nu\,(\sqrt{2st})\,d\alpha(t) \qquad ..(1\cdot1)$$

where $D\nu(z)$ is a parabolic cylinder function. For $\lambda=\nu=0$ integral (1·1) reduces to well known Laplace-Steiltjes integral

$$f(s)=\int_0^{\infty}e^{-st}\,d\alpha(t)$$

We shall althrough assume that λ, ν, s, and γ are all real.

Abelian Theorems

In this section we give two Abelian theorems.

Theorem 2·1

If the integral (1·1) converges for $s>0$ and if $\gamma>0$, $\lambda\geqslant0$; then for any constant A

$$\overline{\lim_{\substack{s\to\infty\\ s\to0+}}}\left|\,s^{\gamma}f(s)-A\,\right|\leqslant\overline{\lim_{\substack{t\to0+\\ t\to\infty}}}\left|\frac{t^{-\gamma}\alpha(t)}{Q}-A\right|$$

where

$$Q^{-1}=\frac{\gamma\Gamma(\gamma+\lambda)\Gamma(\gamma+\lambda+\frac{1}{2})}{\Gamma\left(\gamma+\lambda+\frac{1}{2}-\frac{\nu}{2}\right)}=2^{-\nu/2}\int_0^{\infty}x^{\gamma+\lambda-1}\,e^{-\frac{1}{2}x}\Big[\tfrac{1}{2}D_{+2}(\sqrt{2x})-$$
$$-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2x})\Big]dx \qquad (2\cdot1)$$

and $\alpha(t)=0(t^{-\lambda'})$, $(\lambda\geqslant\lambda')$, $t\to0'$

Proof :—

Since the integral (1·1) converges for $s>0$ we have

$$f(s)=2^{-\nu/2}.s\int_0^\infty (st)^{\lambda-1}.e^{-\frac{1}{2}st}\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\Big(\lambda-\frac{\nu}{2}-\frac{1}{2}\Big)$$
$$D\nu\,(\sqrt{2st})\Big]\alpha(t)\,dt$$

Hence

$$|\,s^{\gamma}f(s)-A\,|=\Big|s^{\gamma+1}.2^{-\nu/2}\int_0^\infty (st)^{\lambda-1}e^{-\frac{1}{2}st}\Big[\tfrac{1}{2}D_{\nu+2}\sqrt{2st}-$$
$$-\Big(\lambda-\frac{\nu}{2}-\frac{1}{2}\Big)D\nu\,(\sqrt{2st})\Big].\Big[\alpha(t)-At^{\gamma}Q\Big]dt\Big|$$
$$\leqslant\Big|Q.2^{-\nu/2}\int_0^T\Big[\frac{\alpha(t).\,t^{-\gamma}}{Q}-A\Big]\Big[(st)^{\gamma+\lambda-1}.\,e^{-\frac{1}{2}st}\times$$
$$\times\Big\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\Big(\lambda-\frac{\nu}{2}-\frac{1}{2}\Big)D\nu(\sqrt{2st})\Big\}d\,(st)\Big]\Big|+$$
$$+s^{\gamma+1}\Big|2^{-\nu/2}\int_T^\infty (st)^{\lambda-1}e^{-\frac{1}{2}st}\Big\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\Big(\lambda-\frac{\nu}{2}-\frac{1}{2}\Big)\times$$
$$\times D\nu(\sqrt{2st})\Big\}\alpha(t)\,dt\Big|+AQ\Big|2^{-\nu/2}\int_T^\infty (st)^{\gamma+\lambda-1}\,e^{-\frac{1}{2}st}\times$$
$$\times\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\Big(\lambda-\frac{\nu}{2}-\frac{1}{2}\Big)D\nu(\sqrt{2st})\Big]d\,(st)\Big|$$
$$=I_1+I_2+I_3$$

$$I_1\leqslant\underset{0\leqslant t\angle T}{\text{l.u.b.}}\Big|\frac{\alpha(t).\,t^{-\gamma}}{Q}-A\Big|\times\Big|Q2^{-\nu/2}\int_0^T (st)^{\gamma+\lambda-1}\times$$
$$\times e^{-\frac{1}{2}st}\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\Big(\lambda-\frac{\nu}{2}-\frac{1}{2}\Big)D\nu(\sqrt{2st})\Big]d\,(st)\Big|$$
$$\leqslant\underset{0\leqslant t\angle T}{\text{l.u.b.}}\Big|\frac{t^{-\gamma}\alpha(t)}{Q}-A\Big|$$

Since the integral (1·1) converges for $s>0$, we can always find a constant M corresponding to any real positive number η such that (Tivari, 1967, Th. 2.4.4)

$$|\,\alpha(t)\,|<M(t^{-\lambda'}e^{\eta t})$$
$$0\leqslant t<\infty;\ \lambda\geqslant\lambda';\ s>\eta.$$

Hence

$$I_2\leqslant Ms^{\gamma+\lambda}\Big|2^{-\nu/2}\int_T^\infty t^{\lambda-\lambda'-1}\,e^{-t\left(\frac{s}{2}-\eta\right)}\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-$$

$$-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2st})\Bigg]\,dt\Bigg|\leqslant M.\,s^{\gamma+\lambda}.\,e^{-T\left(\frac{s}{2}-\eta\right)}\ \Bigg|\ 2^{-\nu/2}$$

$$\int_0^{\infty}(t+T)^{\lambda-\lambda'-1}.\ e^{-st\left(\frac{1}{2}-\frac{\eta}{s}\right)}\Big[\tfrac{1}{2}D_{\nu+2}\sqrt{2s(t+T)}-$$

$$-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu\sqrt{2s(t+T)}\Bigg]dt\Bigg|\ \leqslant\ M_1\,s^{\gamma+\lambda}.\ e^{-T\left(\frac{s}{2}-\eta\right)}$$

$=o(1)$ as $s\to\infty$

since the integrals on the right converges for all values of T and s.

$$I_3=AQ\left|2^{-\nu/2}\int_T^{\infty}(st)^{\gamma+\lambda-1}\,e^{-\frac{1}{2}st}\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)\right.$$

$$\left.D\nu(\sqrt{2st})\Big]^{(d\ st)}\right|\leqslant AQ\left\{\left|G^{3,0}_{2,3}\left(sT\,\middle|\,\begin{matrix}1;\gamma+\lambda-\frac{1}{2}-\frac{\nu}{2}\\0,\gamma+\lambda,\gamma+\lambda+\frac{1}{2}\end{matrix}\right)\right|+\right.$$

$$\left.+\left|\lambda-\frac{\nu}{2}-\frac{1}{2}\right|.\left|G^{3,0}_{2,3}\left(sT\,\middle|\,\begin{matrix}1,\gamma+\lambda+\frac{1}{2}-\frac{\nu}{2}\\0,\gamma+\lambda,\gamma+\lambda+\frac{1}{2}\end{matrix}\right)\right|\right\}$$

$=o(1)$ as $s\to\infty$

since Erdelyi etc. (1954, p. 411)

$$2^{-\nu/2}\int_c^{\infty}(x-c)^{\rho-1}\,.\,(sx)^{\mu}e^{-\frac{1}{2}sx}.D\nu(\sqrt{2sx})\,dx$$

$$=\Gamma(\rho).c^{\rho}.G^{3,0}_{2,3}\times\left(sc\,\middle|\,\begin{matrix}0,\mu+\frac{1}{2}-\frac{\nu}{2}\\-\rho,\mu,\mu+\frac{1}{2}\end{matrix}\right)$$

provided $|\arg.c|\angle\pi$, Re. $\rho>0$.

Hence

$$\overline{\lim_{s\to\infty}}\left|s^{\gamma}f(s)-A\right|\leqslant\underset{0\leqslant t\angle T}{\text{l.u.b.}}\left|\frac{a(t).\,t^{-\gamma}}{Q}-A\right|$$

Since left hand side is independent of T hence taking $T\to0$, we get

$$\overline{\lim_{s\to\infty}}\left|s^{\gamma}f(s)-A\right|\leqslant\overline{\lim_{t\to0+}}\left|\frac{a(t)\,t^{-\gamma}}{Q}-A\right|$$

Again we have

$$\left|s^{\gamma} f(s)-A\right| = \left| s^{\gamma-1} . 2^{-\nu/2} \int_0^{\infty} (st)^{\lambda-1} e^{-\frac{1}{2}st} \left\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st}) - \left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right) D\nu(\sqrt{2st})\right\}\left\{\alpha(t)-At^{\gamma}Q\right\} dt \right|$$

$$\leqslant Q\left|2^{-\nu/2}\, s \int_T^{\infty} (st)^{\gamma+\lambda-1} e^{-\frac{1}{2}st}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st}) - \left(\gamma-\frac{\nu}{2}-\frac{1}{2}\right) D\nu(\sqrt{2st})\right]\left[\frac{\alpha(t)\, t^{-\gamma}}{Q}-A\right] dt\right| + s^{\gamma+1}\left|2^{-\nu/2}\int_0^{T} (st)^{\lambda-1} e^{-\frac{1}{2}st}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st}) - \left(\gamma-\frac{\nu}{2}-\frac{1}{2}\right) D\nu(\sqrt{2st})\right]\alpha(t)\, dt\right| + AQ\, 2^{-\nu/2}\left|\int_0^{T} (st)^{\gamma+\lambda-1} e^{-\frac{1}{2}st}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st}) - \left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right) D\nu(\sqrt{2st})\right] d(st)\right|$$

$$=J_1+J_2+J_3$$

Now

$$J_1 \leqslant \underset{T\leqslant t\angle\infty}{\text{l.u.b.}}\left|\frac{\alpha(t).\, t^{-\gamma}}{Q}-A\right| \times \left|\, 2^{-\nu/2}\, Q \int_T^{\infty} (st)^{\gamma+\lambda-1} . e^{-\frac{1}{2}st} \times \left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st}) - \left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right) D\nu(\sqrt{2st})\right] d(st)\right|,$$

$$\leqslant \underset{T\leqslant t\angle\infty}{\text{l. u. b.}}\left|\frac{\alpha(t)\, t^{-\gamma}}{Q}-A\right|$$

and

$$J_2 = s^{\gamma+1}\left|\, 2^{-\nu/2}\int_0^{T} (st)^{\lambda-1} e^{-\frac{1}{2}st}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st}) - \left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right) D\nu(\sqrt{2st})\right]\alpha(t)\, dt\right|$$

$$\sim s^{\gamma+\lambda}\left|\int_0^{T} t^{\lambda-1}\alpha(t)\, dt\right|$$

$$= o(1) \quad s\to 0 \quad \text{proivded } \gamma+\lambda>0.$$

since $Dy(z)\sim O(1)$ as $|z|\to 0$, and the integral on the right converges under conditions imposed on $\alpha(t)$ for small values of t.

$$J_3=AQ\left| 2^{-\nu/2}\int_0^T (st)^{\gamma+\lambda-1}e^{-\frac{1}{2}st}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)\times\right.\right.$$

$$\left.\left.\times\, D\nu(\sqrt{2st})\right]d\,(st)\right|$$

$$=AQ\left| 2^{-\nu/2}\int_0^{Ts} z^{\gamma+\lambda-1}e^{-\frac{1}{2}z}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2z})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)\times\right.\right.$$

$$\left.\left.\times\, D\nu(\sqrt{2z})\right]dz\right|$$

$$=o\ (1)\ \text{ as } s\to 0.$$

Hence

$$\lim_{s\to 0+}\left| s^{\gamma}f(s)-A\right|\leqslant \underset{T\leqslant t\angle\infty}{\text{l.u.b.}}\left|\frac{t^{-\gamma}a(t)}{Q}-A\right|$$

Since left hand side is independent of T we obtain on taking limit T→∞

$$\lim_{s\to 0+}\left| s^{\gamma}f(s)-A\right|\leqslant \overline{\lim_{t\to\infty}}\left|\frac{t^{-\gamma}a(t)}{Q}-A\right|$$

Hence the theorem.

Lemma 2·1

If $s>\sigma_c>0$, $\gamma+\lambda>0$; (s being real)

$$\frac{\beta}{Q}=2^{-\nu/2}\int_0^{\infty}x^{\gamma+\lambda-1}\cdot e^{-x\left(\frac{1}{2}-\frac{\sigma_c}{s}\right)}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2x})-\right.$$

$$\left.-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2x})\right]dx$$

where

$$\beta={}_2F_1\left(\begin{matrix}\gamma+\lambda,\ \gamma+\lambda+\frac{1}{2}\\ \gamma+\lambda-\frac{1}{2}-\frac{\nu}{2}\end{matrix};\ \frac{\sigma_c}{s}\right)+\frac{\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)}{\gamma}\times$$

$$\times\sum_{n=1}^{\infty}\frac{(\gamma+\lambda)_n\,(\gamma+\lambda+\frac{1}{2})_n}{\left(\gamma+\lambda-\frac{\nu}{2}-\frac{1}{2}\right)_{n+1}\cdot n!}\left(\frac{\sigma_c}{s}\right)^n$$

and Q is as defined in (2·1)

Proof:—

We have Goldstein (1932)

$$2^{-\nu/2}\int_0^{\infty}x^{l-1}e^{-x(\frac{1}{2}+a^2)}\,D\nu(\sqrt{2x})\,dx$$

$$=\frac{\Gamma(l)\,\Gamma(l+\frac{1}{2})}{\Gamma\left(l+\frac{1}{2}-\frac{\nu}{2}\right)}\times{}_2F_1\left(\begin{matrix}l,\ l+\frac{1}{2}\\ l+\frac{1}{2}-\frac{\nu}{2}\end{matrix};\ -a^2\right)$$

provided Re. $l>0$, Re. $(a^2+1)>0$.

Hence

$$2^{-\nu/2}\int_0^{\infty} x^{\gamma+\lambda-1} e^{-x\left(\frac{1}{2}-\frac{\sigma_c}{s}\right)}\left[\tfrac{1}{2}D_{\nu+2}(\sqrt{2x})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2x})\right]dx$$

$$=\frac{\Gamma(\gamma+\lambda)\Gamma(\gamma+\lambda+\frac{1}{2})}{\Gamma\left(\gamma+\lambda+\frac{1}{2}-\frac{\nu}{2}\right)}\Bigg[\left(\gamma+\lambda-\frac{1}{2}-\frac{\nu}{2}\right){}_2F_1\left(\begin{matrix}\gamma+\lambda, \gamma+\lambda+\frac{1}{2}\\ \gamma+\lambda-\frac{1}{2}-\frac{\nu}{2}\end{matrix};\frac{\sigma_c}{s}\right)-$$

$$-\left(\lambda-\frac{1}{2}-\frac{\nu}{2}\right){}_2F_1\left(\begin{matrix}\gamma+\lambda, \gamma+\lambda+\frac{1}{2}\\ \gamma+\lambda+\frac{1}{2}-\frac{\nu}{2}\end{matrix};\frac{\sigma_c}{s}\right)\Bigg]$$

$$=\frac{\gamma\Gamma(\gamma+\lambda)\Gamma(\gamma+\lambda+\frac{1}{2})}{\Gamma\left(\gamma+\lambda+\frac{1}{2}-\frac{\nu}{2}\right)}\Bigg[{}_2F_1\left(\begin{matrix}\gamma+\lambda, \gamma+\lambda+\frac{1}{2}\\ \gamma+\lambda-\frac{1}{2}-\frac{\nu}{2}\end{matrix};\frac{\sigma_c}{s}\right)+$$

$$+\frac{\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)}{\gamma}\sum_{n=1}^{\infty}\frac{(\gamma+\lambda)_n\,(\gamma+\lambda+\frac{1}{2})_n}{\left(\gamma+\lambda-\frac{1}{2}-\frac{\nu}{2}\right)_{n+1}\cdot n!}\left(\frac{\sigma_c}{s}\right)^n\Bigg]$$

$$=\frac{\beta}{Q}.$$

Theorem 2·2

If the integral (1·1) converges for $s>\sigma_c$ (s being real) and if $\gamma+\lambda'>0$, $\lambda\geqslant\lambda'$; $\gamma+\lambda+\frac{\nu}{2}+1>0$, then

$$\overline{\lim_{s\to\sigma_c+}}\left|\frac{s^{\gamma+1}.\,f(s)}{\beta}-A\sigma_c\right|\leqslant\lim_{t\to\infty}\left|\frac{\alpha(t)\;t^{-\gamma}.\,e^{-\sigma_c t}}{Q}-A\right|$$

where β and Q are as defined in Lemma 2·1.

Proof:—

Since the integral (1·1) converges for $s>\sigma_c$, we have

$$f(s)=2^{-\nu/2}.\,s\int_0^{\infty}(st)^{\lambda-1}e^{-\frac{1}{2}st}.\Bigg[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)\times$$

$$\times D\nu(\sqrt{2st})\Bigg]\alpha(t)\,dt.$$

Now

$$\left|\frac{s^{\gamma+1}f(s)}{\beta}-A\,\sigma_c\right|$$

$$=2^{-\nu/2}\Bigg|\Bigg[\frac{s^{\gamma+1}(s-\sigma_c)}{\beta}\int_0^{\infty}(st)^{\lambda-1}e^{-\frac{1}{2}st}\left\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)\times\right.$$

$$\times D\nu(\sqrt{2st}\,)\ \Big\}\,a(t)\,dt\,\Big]+\frac{s^{\gamma+1}.\,\sigma_c}{\beta}\int_0^T (st)^{\lambda-1}e^{-\frac{1}{2}st}\ \Big\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-$$

$$-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2st})\Big\}\ \Big\{\,a(t)-At^{\gamma}Q\,.\,e^{\sigma_c t}\ \Big\}\ dt+\frac{\sigma_c Q}{\beta}\int_T^{\infty}(st)^{\gamma+\lambda-1}\times$$

$$e^{-st\left(\frac{1}{2}-\frac{\sigma_c}{s}\right)}\ \Big\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2st})\Big\}\times$$

$$\times\left[\frac{t^{-\gamma}e^{-\sigma_c t}.\,a(t)}{Q}-A\right]d(st)\Big|$$

$$\leqslant\frac{s^{\gamma+1}(s-\sigma_c)}{\beta}\Big|\ 2^{-\nu/2}\int_0^{\infty}(st)^{\lambda-1}e^{-\frac{1}{2}st}\,.\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\tfrac{1}{2}\right)\times$$

$$\times D\nu(\sqrt{2st})\,\Big]\,a(t)\,dt\,\Big|+\frac{s^{\gamma+1}.\sigma_c}{\beta}\,2^{-\nu/2}\int_0^{\infty}\Big|(st)^{\lambda-1}e^{-\frac{1}{2}st}\ \Big\{\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-$$

$$-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2st})\Big\}\Big|\ a(t)-At^{\gamma}Q\,e^{\sigma_c t}\ \Big|\,dt+\ \frac{\sigma_c.\,\beta}{Q}.\,2^{-\nu/2}\times$$

$$\times\int_0^{\infty}(st)^{\gamma+\lambda-1}e^{-st\left(\frac{1}{2}-\frac{\sigma_c}{s}\right)}\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)\times$$

$$\times D\nu(\sqrt{2st})\,\Big]\left|\frac{t^{-\lambda}e^{-\sigma_c t}.\,a(t)}{Q}-A\,\right|\,d\,(st)$$

$=I_1+I_2+I_3$.

Now

$$I_1=\frac{s^{\gamma+1}(s-\sigma_c)}{\beta}\Big|\ 2^{-\nu/2}\int_0^{\infty}(st)^{\lambda-1}e^{-\frac{1}{2}st}\,.\Big[\tfrac{1}{2}D_{\nu+2}(\sqrt{2st})-$$

$$-\left(\lambda-\frac{\nu}{2}-\frac{1}{2}\right)D\nu(\sqrt{2st})\,\Big]\,a(t)\,dt\,\Big|$$

$=o\ (1)$ as $s\to\sigma_c$ provided $\gamma+\lambda+\frac{\nu}{2}+1>0$ since the integral on the right is always convergent for $s>\sigma_c$ and $\beta\to\infty$ as $s\to\sigma_c+$ provided $\gamma+\lambda+\frac{\nu}{2}+1>0$.

We now consider I_2, since the integral (1·1) converges for $s>\sigma_c$ we have for $\lambda\geqslant\lambda'$ (Tivari, 1967; Th. 2.4.4)

$$\Big|\ a(t)-At^{\gamma}\,Q\,e^{\sigma_c t}\ \Big|\ \angle\ M^{-\lambda'}\ e^{\sigma_c t}\qquad(0\leqslant t\angle\infty)$$

Hence

$$I_2 \leqslant \frac{\sigma_c .\ s^{\gamma+\lambda'} .\ M}{\beta} \left| 2^{-\nu/2} \int_0^{\frac{T}{s}} .\ x^{\lambda-\lambda'-1}\, e^{-x\left(\frac{1}{2}-\frac{\sigma_c}{s}\right)} \times \right.$$

$$\left. \times \left[\tfrac{1}{2} D_{\nu+2}(\sqrt{2st}) - \left(\lambda - \frac{\nu}{2} - \frac{1}{2} \right) D\nu(\sqrt{2x}) \right] dx \right|$$

$=o\ (1)$ as $s \to \sigma_c +$ provided $\gamma+\lambda+\frac{\nu}{2}+1>0$, since the integral on the right is always convergent for $s<\sigma_c$ and $\beta \to \propto$ as $s \to \sigma_c +$ provided $\gamma+\lambda+\frac{\nu}{2}+1>0$. Now considering I_3, we have

$$I_3 \leqslant \underset{T \leqslant t \angle \propto}{\text{l.u.b.}} \left| \frac{t^{-\gamma} e^{-\sigma_c t} .\ a(t)}{Q} - A \right| \times \frac{\sigma_c .\ Q}{\beta}\, 2^{-\nu/2} \int_T^{\propto} (st)^{\gamma+\lambda-1} \times$$

$$\times e^{-st\left(\frac{1}{2}-\frac{\sigma_c}{s}\right)} \left[\tfrac{1}{2} D_{\nu+2}(\sqrt{2st}) - \left(\lambda - \frac{\nu}{2} - \frac{1}{2} \right) D\nu(\sqrt{2st}) \right] d\,(st).$$

$$\leqslant \underset{T \leqslant t \angle \propto}{\text{l.u.b.}} \left| \frac{t^{-\gamma} e^{-\sigma_c t} .\ a(t)}{Q} - A \right|$$

Hence

$$\overline{\lim_{s \to \sigma_c +}} \left| \frac{s^{\gamma+1} .\ f(s)}{\beta} - A\ \sigma_c \right| \leqslant \overline{\lim_{T \leqslant t \angle \propto}} \left| \frac{t^{-\gamma} e^{-\sigma_c t} .\ a(t)}{Q} - A \right|$$

The left hand side is independent of T hence we can take $T \to \propto$.

Hence the theorem.

TAUBERIAN THEOREM

In this section we prove a Tauberian theorem. The following Lemma is immediate.

Lemma 3·1 If $x>0$

$$\frac{\Gamma(\frac{1}{2})}{\Gamma\left(\frac{1}{2}-\frac{\nu}{2}\right)} - 2^{-\nu/2}\, e^{-x/2} .\ D\nu\,(\sqrt{2x}\,) \leqslant \frac{2\pi^{\frac{1}{2}}}{\Gamma\left(-\frac{\nu}{2}\right)}\, x^{\frac{1}{2}} + \frac{\Gamma(-\frac{1}{2})}{\Gamma\left(-\frac{1}{2}-\frac{\nu}{2}\right)} .\, x$$

Proof:—

Let us consider the function

$$F(x) = \frac{\Gamma(\frac{1}{2})}{\Gamma(\frac{1}{2}-\nu/2)} - 2^{-\nu/2}\, e^{-x/2} .\ D\nu(\sqrt{2x}) - \frac{2\pi^{\frac{1}{2}}}{\Gamma(-\nu/2)}\, x^{\frac{1}{2}} - \frac{\Gamma(-\frac{1}{2})}{\Gamma(-\frac{1}{2}-\nu/2)}\, x.$$

Since

$$\frac{d}{dx}\left[e^{-x/2}\,\mathrm{D}\nu(\sqrt{2x})\right]=-(2x)^{-\frac{1}{2}}e^{-x/2}\,.\,\mathrm{D}_{\nu+1}(\sqrt{2x})$$

$$\mathrm{F}'(x)=2^{-\nu/2-\frac{1}{2}}\,.\,x^{-\frac{1}{2}}.e^{-\frac{1}{2}x}.\,\mathrm{D}_{\nu+1}(\sqrt{2x})-\frac{\pi^{\frac{1}{2}}.\,x^{-\frac{1}{2}}}{\Gamma(-\nu/2)}-\frac{\Gamma(-\frac{1}{2})}{\Gamma(-\frac{1}{2}-\nu/2)}$$

and

$$\mathrm{F}''(x)=-2^{-\nu/2-3/2}x^{-3/2}\,e^{-\frac{1}{2}x}.\mathrm{D}_{\nu+1}(\sqrt{2x})-2^{-\nu/2-1}\,.\,x^{-1}\,.\,e^{-\frac{1}{2}x}\times$$

$$\times\,\mathrm{D}_{\nu+2}(\sqrt{2x})+\frac{\pi^{\frac{1}{2}}x^{-3/2}}{2\Gamma(-\nu/2)}\,.$$

hence

F(0)=0, F′(0)=0 and F″(0)$\angle$0 and therefore F(x) has a maximum at x=0 and since F(0)=0 its value is less than or equal to zero. This establishes our Lemma.

Theorem 3·1.

If $\alpha(t)\ \varepsilon$ L in (0, R) for every positive R and if the integral (1·1) converges for $s>0$ (s being real), then the conditions

(i) $\lim\limits_{s\to 0+}\left[s^{-\lambda}f(s)\right]=\mathrm{A},$

and

(ii) $\alpha(t)=o\,(t^{-\lambda-1})\ t\to\infty;$

imply

$$\lim_{s\to 0+}\left[s^{-\lambda}f(s)\right]\equiv\frac{\Gamma(\frac{1}{2})}{\Gamma(\frac{1}{2}-\nu/2)}\int_0^\infty t^{\lambda}\alpha(t)dt=\mathrm{A}$$

Proof:—

Under the hypothesis (ii) of the theorem we have

$$t^{-1}\int_0^t {}^{\lambda+1}\left|\,\alpha(u)\,\right|du=o\ (1)$$

therefore the difference

$$\frac{\Gamma(\frac{1}{2})}{\Gamma(\frac{1}{2}-\nu/2)}\int_0^t u^{\lambda}\,\alpha(u)\,du-t^{\lambda}.\,2^{-\nu/2}\int_0^\infty\left(\frac{u}{t}\right)^{\lambda}e^{-\frac{1}{2}\,u/t}.\mathrm{D}\nu\left(\sqrt{2\frac{u}{t}}\right)\alpha(u)du$$

$$=\int_0^t u^{\lambda}\,\alpha(u)\left[\frac{\Gamma(\frac{1}{2})}{\Gamma\,(\frac{1}{2}-\nu/2)}-2^{-\nu/2}\,e^{-\frac{1}{2}\,u/t}.\mathrm{D}\nu\left(\sqrt{2\frac{u}{t}}\right)\right]du-$$

$$-2^{-\nu/2}\int_t^\infty u^{\lambda}e^{-\frac{1}{2}\,u/t}.\mathrm{D}\nu\left(\sqrt{2\frac{u}{t}}\right)\alpha\,(u)\,du$$

$=\mathrm{I}_1+\mathrm{I}_2.$

$$I_1 \leqslant \frac{2\Gamma(\frac{1}{2})}{\Gamma(-\nu/2)} t^{-\frac{1}{2}} \int_0^t u^{\lambda+\frac{1}{2}} \mid a(u) \mid du + \frac{\Gamma(-\frac{1}{2})}{\Gamma(-\frac{1}{2}-\nu/2)} t^{-1} \int_0^t u^{\lambda+1} \mid a(u) \mid du$$

$$= o\ (1) \quad t \to \propto$$

and

$$\mid I_2 \mid \ \leqslant \underset{t \leqslant u \angle \propto}{\text{l.u.b.}} \left| a(u).\, u^{\lambda+1} \right| \int_t^{\propto} u^{-1} e^{-\frac{1}{2}\, u/t}.\, D\nu\left(\sqrt{2\frac{u}{t}}\right) du$$

$$\leqslant M \underset{t \leqslant u \angle \propto}{\text{l.u.b.}} \left| a(u).\ u^{\lambda+1} \right|$$

$$= o\ (1) \quad t \to \propto.$$

Hence

$$\overline{\lim_{t \to \propto}} \left[\frac{\Gamma(\frac{1}{2})}{\Gamma(\frac{1}{2}-\nu/2)} \int_0^t u^{\lambda} \alpha(u)\ du - 2^{-\nu/2} \int_0^{\propto} u^{\lambda} e^{-\frac{1}{2}u/t}\, D\nu\left(\sqrt{2\frac{u}{t}}\right) \times \right.$$
$$\left. \times\ \alpha(u)\ du \right] = o\ (1)$$

or

$$\frac{\Gamma(\frac{1}{2})}{\Gamma(\frac{1}{2}-\nu/2)} \int_0^{\propto} u^{\lambda} \alpha(u)\ du$$

$$= \lim_{s \to 0+} s^{-\lambda} 2^{-\nu/2} \int_0^{\propto} (su)^{\lambda} e^{-\frac{1}{2}su}.\, D\nu(\sqrt{2su})\ \alpha(u)\ du$$

$$= \lim_{s \to 0+} \left[s^{-\lambda} f(s) \right]$$

$$= A$$

Thus the theorem is proved.

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A COMPARATIVE STUDY OF THE $S_2O_8^{2-}$—INDUCED REDUCTION OF MERCURIC CHLORIDE BY DIFFERENT ORGANIC ACIDS AND THE EFFECT OF DIFFERENT SUBSTITUENT GROUPS ON THE REDUCTION

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Summary

A comparative study of the $S_2O_8^{2-}$—induced reduction of mercuric chlorid by organic acids, having different substituent groups, reveals that though th principal mechanistic steps in all the cases are almost identical, the reductio being attributed to CO_2^- radical, the transient $S_2O_8^{2-}$—oxidation steps differ depending upon the organic acid employed. It has been further observed tha the rate of reduction is a more significant function of the substituent in the acid molecule. Addition of $-OH$, $-NH_2$ in the acid molecule increases the reduction rate while the reverse is true for the substitution of CH_2— and —COOH.

Introduction

Peroxodisulphate induced reduction of mercuric chloride by different organic acids has been under investigation in this Laboratory for several years and has been the subject of several papers. The kinetic data obtained with oxalic (11), lactic (4), malic (5), maleic (9), tartaric (14) and amino acids (6) have been employed to elucidate the mechanism of the respective reactions. It has been found that though the principal mechanistic steps in all the cases are almost identical, reduction being attributed to the CO_2^- radical (1), the transient $S_2O_8^{2-}$—oxidation steps differ, depending upon the organic acid employed.

It has been further observed that the presence of a substituent group in the acid molecule, significantly influences the rate of induced reduction of mercuric chloride. This suggests that the rates are a more significant function of the substituent in the acid molecule.

The aim herein is to summarise the results of these studies and to present the mechanism advanced such as to throw light on the effect of different substituent groups, in the acid molecule, on the rate of mercuric chloride reduction.

OBSERVATIONS AND DISCUSSION

The quantitative data obtained for the reduction of mercuric chloride by different organic acids, induced by $S_2O_8^{2-}$ ion, under identical conditions of reactant concentrations and temperature have been summarised in the following table. From such a table, much can be learnt about the influence of the substituent on the induced reduction of mercuric chloride and more quantitative conclusions, which elaborate on this attribute of the substituent groups, can be readily drawn.

TABLE 1

Acid	Activation parameters for the Acid-$K_2S_2O_8$ reaction 0·02 M Concs.			Amount of calomel precipitated in 120 mins. under the inductive influence of 0·02M $K_2S_2O_8$
	10^3k_1 (70°C)	E Kcals	A	10^3 (moles l^{-1}) Temp.=60°C
Formic*	26·16	38·5	$6{\cdot}42\times10^{22}$	1·400
Formic**	...	...	...	0·300
Acetic	3·34	25·6	$5{\cdot}93\times10^{13}$	nil
Propionic	2·88	31·3	$1{\cdot}95\times10^{17}$	nil
Butyric	4·29	29·1	$1{\cdot}12\times10^{16}$	nil
Oxalic	6·77	39·9	$3{\cdot}16\times10^{22}$	9·850
Malonic	2·92	28·4	$2{\cdot}85\times10^{15}$	0·300
Succinic	2·50	29·5	$1{\cdot}31\times10^{16}$	in traces
Lactic	8·75	20·3	$5{\cdot}14\times10^{16}$	1·100
Malic	7·98	21·6	$1{\cdot}82\times10^{11}$	2·000
Tartaric	13·58	41·2	$1{\cdot}65\times10^{22}$	5·000
Maleic	5·48	30·3	$8{\cdot}34\times10^{16}$	1·350
Fumaric (0·02 M)	...	...	...	0·700
Glycine	5·75(40°C)	25·7	$3{\cdot}63\times10^{15}$	5·425***

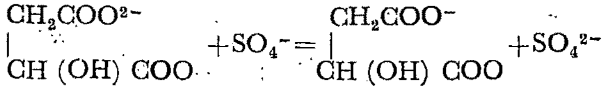
* Without the inductor $K_2S_2O_8$
** With the inductor $K_2S_2O_8$
*** In presence of 0·005 M $CuSO_4$

From these quantitative data certain facts stand out:

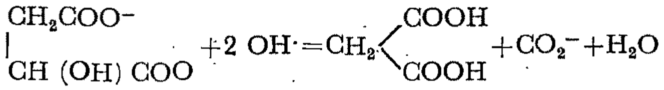
I. The amount of mercuric chloride reduced is greatest in the case of oxalic acid than in other acids. Evidently, this is due to the rate of formation of CO_2^- radical being faster in the case of oxalic acid, since this active species (responsible for the reduction) is readily formed from $C_2O_4^{2-}$ ions which are already present in the reaction solution, as may be seen from the mechanistic steps 1 (a and b): (12)

1. (a) $S_2O_8^{2-}=2\,SO_4^-$
(b) $SO_4^-+C_2O_4^{2-}=SO_4^{2-}+CO_2^-+CO_2$

In the case of other acids, the CO_2^- radical is, however, generated from the products obtained after different oxidation stages of the acids. The various steps in the oxidation mechanism are of considerable interest in their own right and are therefore, briefly reviewed. For example, in malic acid oxidation by peroxodisulphate ion, it is seen that CO_2^- radical is produced after steps 2 (a – d). (2)

2. (a) $S_2O_8^{2-}=2\,SO_4^-$
(b) $SO_4^-+H_2O=HSO_4^-+OH^\cdot$
(c)


$$\begin{array}{l}CH_2COO^{2-}\\ |\\ CH\,(OH)\,COO\end{array}+SO_4^-=\begin{array}{l}CH_2COO^-\\ |\\ CH\,(OH)\,COO\end{array}+SO_4^{2-}$$

(d)


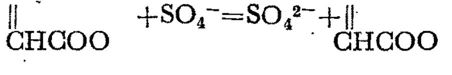
$$\begin{array}{l}CH_2COO^-\\ |\\ CH\,(OH)\,COO\end{array}+2\,OH^\cdot=CH_2\!\left\langle\begin{array}{l}COOH\\ COOH\end{array}\right.+CO_2^-+H_2O$$

Similarly the oxidation stages of other organic acids, reffered to above, caused either by the sulphate radical –ion generated in reaction (a) or by hydroxyl radical formed by reaction of sulphate radical ion with water (as shown in Seq. 2 b), are mechanistically reviewed below:

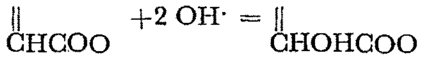
Lactic acid oxidation (3)

3. (a) $S_2O_8^{2-}=2\,SO_4^-$
(b) $SO_4^-+H_2O=HSO_4^-+OH^\cdot$
(c) $OH^\cdot+CH_3CH\,(OH)\,COO^-=CH_3CHO+CO_2^-+H_2O$

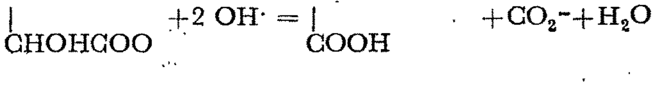
Maleic acid oxidation (8—9)

4. (a) $S_2O_8^{2-}=2\,SO_4^-$
(b) $SO_4^-+H_2O=HSO_4^-+OH^\cdot$
(c)


$$\begin{array}{l}CHCOO^{2-}\\ \|\\ CHCOO\end{array}+SO_4^-=SO_4^{2-}+\begin{array}{l}CHCOO^-\\ \|\\ CHCOO\end{array}$$

(d)


$$\begin{array}{l}CHCOO^-\\ \|\\ CHCOO\end{array}+2\,OH^\cdot=\begin{array}{l}CHOHCOO^-\\ \|\\ CHOHCOO\end{array}$$

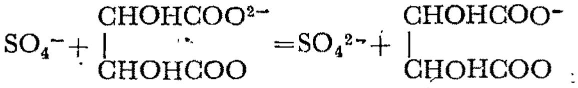
(e)


$$\begin{array}{l}CHOHCOO^-\\ |\\ CHOHCOO\end{array}+2\,OH^\cdot=\begin{array}{l}CHOHCOOH\\ |\\ COOH\end{array}+CO_2^-+H_2O$$

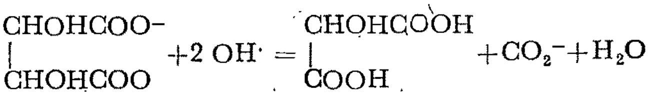
Tartaric acid oxidation (13)

5. (a) $S_2O_8^{2-} = 2\,SO_4^-$

(b) $SO_4^- + H_2O = HSO_4^- + OH^{\cdot}$

(c)


$$SO_4^- + \begin{array}{l} CHOHCOO^{2-} \\ | \\ CHOHCOO \end{array} = SO_4^{2-} + \begin{array}{l} CHOHCOO^- \\ | \\ CHOHCOO \end{array}$$

(d)


$$\begin{array}{l} CHOHCOO^- \\ | \\ CHOHCOO \end{array} + 2\,OH^{\cdot} = \begin{array}{l} CHOHCOOH \\ | \\ COOH \end{array} + CO_2^- + H_2O$$

Cu^{2+}—catalysed glycine oxidation: (7)

6. (a) $Cu^{2+} + S_2O_8^{2-} = Cu^{3+} + SO_4^{2-} + SO_4^-$

(b) $Cu^{II}(CH_2NH_2CO_2)_2 + S_2O_8^{2-} = \left[Cu^{III}(CH_2NH_2CO_2)_2\right]^+ + SO_4^- + SO_4^{2-}.$

(c) $SO_4^- + H_2O = HSO_4^- + OH^{\cdot}$

(d) $\left[Cu^{III}(CH_2NH_2CO_2)_2\right]^+ + SO_4^- = \left[Cu^{II}(CH_2NH_2CO_2)\right]^+ + SO_4 + CH_2NH_2CO_2^-$

(e) $CH_2NH_2CO_2^- + OH^{\cdot} = HCHO + NH_3 + CO_2^-$

II. The lowest member of the homologous series is most reducing. Introduction of CH_2^- group in the acid molecule decreases its reducing power, since the order of mercuric chloride reduction by different homologues in a series is as :

(a) Formic acid reduces directly, while its higher homologues do not, even under the inductive influence of $S_2O_8^{2-}$.

(b) Reduction by oxalic acid malonic acid, while higher homologues do not reduce at all.

Apparently the addition of CH_2 makes the acid molecule more complicated to be oxidised and as a result, its capacity to reduce mercuric chloride is adversely affected.

III. Propionic and succinic acids do not reduce mercuric chloride, whereas lactic and malic acids do so readily. These observations clearly suggest that the substitution of —OH group in the acid molecule favours the reduction rate. This fact finds further confirmation from the strickingly different rates of reduction obtained with tartaric and malic acids; reduction rate being greater with the former i.e., the dihydroxy acid. With introduction of the —OH group, it seems that the acid is oxidised readily by $S_2O_8^{2-}$, with the result that the products, from which the CO_2^- radical is obtained, are formed earlier and so the rate of reduction is faster.

IV. On the contrary, citric acid, an acid having an —OH group in its molecule brings the induced reduction of mercuric chloride very slowly. This may be attributed to the presence of three carboxylic groups in the acid molecule. The inhibiting effect of —COOH group is clearly evidenced from the fact that while formic acid reduces mercuric chloride even without an inducing ion, oxalic acid is unable to do so, and it is only under the inductive influence of an oxidant ($S_2O_8^{2-}$), that it reduces mercuric chloride. In citric acid the suppressing effect of the three carboxylic groups overweighs the favourable effect of —OH group and hence the rate of reduction of mercuric chloride is much slowed down in presence of this acid.

V. Acetic acid does not reduce at all. Lactic acid brings the reduction at a reasonable rate, whereas, glycine reduces only when catalysed by copper ions. These observations show that both, —OH and NH_2— substituents in the acid molecule, favour the $S_2O_8^{2-}$ induced reduction of mercuric chloride; the effect of —NH_2 group being lesser. In the case of lactic acid, the products, from which the active species i.e., CO_2^- responsible for the reduction of mercuric chloride, are obtained directly on oxidation [Seq. 3 (a—c)], whereas in glycine, the active species is obtainable only from the complex formed in between copper ion and glycine [Seq. 6 (a—e)].

VI. The frequency factor is interestingly associated with the reducing power of the acid (table 1). In a homologoues series, the acid having the highest value of the frequency factor, has the greatest rate of reduction. The above conclusions arrived at, also find support from the work of P. C. Mathur and O.P. Bansal carried out in the same Laboratories, on the MnO_4^- induced reduction of mercuric chloride by different organic acids (10).

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Abstract of Theses

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STUDIES ON THE BIOLOGY AND COMPARATIVE MORPHOLOGY OF SOME AMPHISTOMATOUS PARASITES OF DOMESTIC ANIMALS*

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Large number of trematodes have been reported from Indian cattle, buffaloes, sheep, goats and other domestic animals. They belong to three major groups, viz. amphistomes, schistosomes and liverflukes. Of these, amphistomes are the most common and at times cause, as immature worms, heavy mortality among livestock. They are mostly found to parasitise either the digestive tract, specially the rumen and reticulum in the adult stage and intestine in the immature stage, or the bile ducts of the hosts. No effective anthelmintics are known for the treatment of amphistomiasis. For the formulation of measures for the control of amphistome infections a detailed knowledge of their life cycles and the incidence of larval infection in their intermediate hosts is essential.

The present studies were, therefore, undertaken on the occurrence of adults and larval amphistomes in domesticated animals and in aquatic snails, the life histories of three species of amphistomes of ruminants and the morphology and development of some larval amphistomes. Studies have also been conducted on the incidence, seasonal variations of amphistome infections in aquatic snails. The thesis is divided into seven parts containing 23 Plates and 34 Tables.

PART I

1. A brief historical account of the amphistome cercariae and of the studies conducted on their life histories in India and abroad has been given. The amphistome cercariae belonging to the "Pigmentata" and "Diplocotylea" groups, reported from India and abroad have been listed.

2. The methods commonly employed in the study of adult amphistomes, their eggs and larval stages have been used in the studies. The methods employed have been briefly indicated in the thesis.

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* Abstract of the Thesis approved for the degree of Doctor of Philosophy of Agra University in 1968.

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PART II

3. The life history of *Ceylonocotyle dicranocoelium* (Fischoeder, 1901) Nasmark, 1937 has been elucidated and described in detail. The life history was previously unknown.

The freshly deposited eggs of the parasite measure 0·143 mm. × 0·077 mm. on an average. They hatch in 9 to 14 days in water and 12 to 18 days in faecal cultures. The development of the miracidium and its detailed morphology have been described.

The number of epithelial cells is 20 which are arranged in four tiers (i.e. 6, 8, 4, 2=20). Two pairs of penetration glands, i.e. one pair on either side of the primitive gut, are present. *Bulimus pulchellus* has been found to act as the intermediate snail host of the parasite. The sporocysts mature in the snail host in 8 to 10 days, post infection. The rediae, containing developing cercariae, are formed by the 17th day of infection. They are without pigment and locomotor appendages. The cercariae, which belongs to the "Pigmentata" group of Sewell (1922), had not been described before. The morphology of the sporocyst, redia and cercaria has been described in detail.

The fresh metacercaria is brownish in appearance but becomes dark brown with age. Its spherical body, with rough outermargin, measures 0·53 to 0·58 mm. in diameter.

The metacercariae were fed to a clean kid. The faeces of the kid became positive for amphistome eggs in 88 days after infection. The adult worms, recovered from the rumen of the experimental kid, were identified as belonging to *Ceylonocotyle dicranocoelium*. The percentage of development of the metacercariae into adult parasite was 35·1%. The kid was kept under observation till its death. A mild infection with this parasite caused no clinical symptoms in the host.

A short historical account of the genus *Ceylonocotyle* Nasmark (1937) and a brief description of the adult *Ceylonocotyle dicranocoelium* are also included.

PART III

4. The life history of *Ceylonocotyle scoliocoelium* (Fischoeder, 1904) Nasmark, 1937 has been worked out in detail.

In the majority of the freshly deposited eggs early segmentation (mostly 4 to 16 celled stage) is observed. The miracidia develop and hatch out of the eggs within 10 to 13 days in water cultures and 12 to 18 days in faecal cultures. The morphology of the miracidium has been described in detail. There are twenty epithelial cells arranged in four tiers, i.e. 6, 8, 4, 2=20. There are two pairs of penetration glands in the miracidium, one pair on either side of the primitive gut. The longevity of the miracidia in different media has been studied.

Bulimus pulchellus has been found to serve as its intermediate host. The reaction and behaviour of the mircaidia towards the snail have been described. The sporocysts mature in 12 days of infection. The unpigmented rediae, without locomotor appendages and containing developing cercariae, measure 0 571—0·70 mm. ×0·153—0·23 mm. Daughter rediae are absent. The morphology of the immature cercariae has been described.

The mature cercaria belongs to the "Pigmentata" group of Sewell (1922) and has been identified as *Cercaria bulimusi* Peter and Srivastava (1955). A detailed morphological account of the cercaria has been furnished. The shedding of the cercariae, their swimming movements and process of encystment have been described.

The metacercariae, on an average, measure 0·4 mm. in diameter. When fed to clean kids, the metacercariae developed into adult *Ceylonocotyle scoliocoelium* within 125 days of the infection. No clinical symptoms developed in the final host. The development of the metacercariae into adult in the definitive host was 56·4%. A brief description of the adult parasite has also been given.

PART IV

5. The life history of *Gigantocotyle bathycotyle* (Fischoeder, 1901) Nasmark, 1937, an amphistome in the bile ducts of ruminants, has been described in detail. It has not been previously worked out.

Freshly deposited egg contains a fully developed ovum which is usually located at varying positions in its anterior half. In the months of May and June, the miracidia develop and hatch in 9 to 11 and 12 to 16 days in water and faecal cultures, respectively. The development and hatching of the miracidia have been studied. The process of hatching of the miracidia, their activities while swimming and their longevity in different media have been followed. A detailed morphology of the miracidium is given. The epithelial cells are twenty in number and their arrangement in four tiers is represented by the formula 6, 8, 4, 2=20. Two pairs of penetration glands, one pair on either side of the primitive gut, are present.

Gyraulus convexiusculus has been found to be the intermediate snail host in nature and in experimental infections. The behaviour of the miracidia towards the snail host has been studied. Mature sporocysts develop in the snail in eight days after infection. The development of the redia in sporocyst is rapid. In 15 days after infection, the rediae become free in the snail tissue. The wall of the redia is thick and pigmented, and locomotor appendages are absent.

The cercaria belongs to the "Pigmentata" group of Sewell (1922) and is similar to *Cercaria gyraulusi* Peter and Srivastava (1955). The emergence of mature cercariae, their general activities and process of encystment have been studied. The snail sheds about 6 to 15 cercariae per day, The metacercariae measure on an average 0·253 mm. in diameter. The metacercariae, when fed to two clean kids, developed into adult *G. bathycotyle*, in 90 to 103 days, post infection. The percentage of development of the adult worms in experimental kid has been found to be 9·94% and 3·13%.

The specific validity of *G. bathycotyle* had been questioned by certain workers. It has, however, been established on the basis of the characters of some of its larval stages described in the thesis. A short historical account of *G. bathycotyle* and a description of the adult worm have also been given.

PART V

6 The distinguishing characters of the two groups of amphistome cercariae, i.e. "Pigmentata" and "Diplocotylea", have been briefly discussed. It has been concluded that the differential diagnosis of the two groups of amphistome cercariae depends only on a single constant character, namely the presence of an excretory cross-connection between two main excretory trunks in the "Pigmentata" group and the absence of the same in the "Diplocotylea" group.

7. *Cercaria onkari* n. sp., was collected from *Indoplanorbis exustus*. It belongs to the "Diplocotylea" group of Sewell (1922). Dark black patches of pigment are found in the cercaria in the second fifth of its body from the anterior end. They are mostly around the oesophageal bulb. The rudimentary oral pouches are located in the dorso-lateral part of the oral sucker. The major part of the posterior portion and a small part of the anterior portion of the main excretory tubes are completely devoid of excretory granules. The redia possesses two pairs of locomotor appendages and its gut is filled with uniformly distributed dark pigment in the form of flecks.

The morphology of the cercaria, redia and metacercaria has been described.

8. Sewell (1922) described the digestive and excretory systems of *Cercariae indicae XXXII.* The description has been supplemented by a detailed morphological account of its reproductive system, radial stages and of its metacercaria.

9. The excretory system of *Cercaria chungathi* Peter and Srivastava (1955) has been described, showing some interesting variations therein. The difference observed in the course of vas efference has been mentioned.

PART VI

10. A survey of the cercarial infections in aquatic snails in Bareilly district during a period of three years, i.e. from October, 1963 to September, 1966 was carried out.

Of a large collection of 17, 074 snails, belonging to seven species: *Melania (T) lineatus, M. (T.) tuberculatus, Lymnaea auricularia, L. luteola, Bulimus pulchellus,* *Indoplanorbis exustus*, *Gyraulus convexiusculus* and collected from different sources, only 1·11% were found to be positive for amphistome infection. 5·04% of the snails were found harbouring cercariae of other trematodes. The last four species of snails were found infected with several species of amphistome cercariae. In all following nine species of amphistome cercariae were collected in Bareilly District, out of which last two (marked*) proved to be new to science—

(i) *Cercariae indicae XXVI* Sewell, 1922.
(ii) *Cercariae indicae XXIX* Sewell, 1922.
(iii) *Cercariae indicae XXXII* Sewell, 1922.
(iv) *Cercaria bulimusi* Peter and Srivastava, 1955.
(v) *Cercaria chungathi* Peter and Srivastava, 1955.
(vi) *Cercaria gyraulusi* Peter and Srivastava, 1955.
(vii) *Cercaria pseudodisci collinsi* Peter and Srivastava, 1955.
*(viii) *Cercaria onkari* n. sp.
*(ix) *Cercaria* of *Ceylonocotyle dicranocoelium.*

11. Seasonal variations in the incidence of amphistome and other trematode infections in aquatic snails during different seasons of the year have been studied over a period of three years, i.e. from October, 1963 to September, 1966.

The year was divided into four seasons according to Metrological Department, Poona (India):—

(1) Winter season (December, January and February),
(2) Hot weather season (March to May),
(3) South-West monsoon season (June to September), and
(4) Post-monsoon season (October and November).

Daily records of maximum and minimum temperatures of open field and laboratory, annual rainfall and relative atmospheric humidity, both in morning and evening were maintained.

It has been observed that the occurrence of amphistome infection is seasonal; the incidence of infection being high both in the South-West monsoon and Post-monsoon seasons. As far the individual species, *Indoplanorbis exustus* was found heavily infected (12·43%) in the South-West monsoon season and lightly (4·22%) in winter. *Gyraulus convexiusculus* carried only light infections, the maximum (3·46%) in Post-monsoon and minimum (0·49%) in Winter. No amphistome infection was found in Hot weather.

Trematode infections, other than of amphistomes have been found to be high both in Post-monsoon and Winter seasons.

It has been found that the percentage of infection in a particular species of snail is not constant either in different months of a season or during the same seasons in different years.

12. A few cases of double infections in snails have also been recorded.

PART VII

13. A survey of amphistomes occurring in domestic animals during the period of three years, i.e. from October 1963 to September, 1966 was carried out. In all, eighteen species of amphistomes representing five subfamilies of the family Paramphistomidae were collected from cattle, buffaloes, sheep, goats, horses and pigs. They have been listed together with their specific hosts and location.

N.B.—The details of the investigations are under publication in form of 'papers' in various journals.

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KINETICS AND MECHANISM OF THE REDUCTION OF MERCURIC CHLORIDE BY ORGANIC ACIDS, INDUCED BY POTASSIUM PEROXODISULPHATE AND INFLUENCE OF SUBSTITUENT GROUPS, IN THE ACID MOLECULE, ON THE REACTION MECHANISM[1]

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SUMMARY

The $S_2O_8^{2-}$ -induced reduction of mercuric chloride by various organic acids—lactic, malic, maleic and glycine have been studied from viewpoint of kinetics. Detailed experimental studies on the rate of such reactions and its dependence upon various factors, ascertained under conditions of varying concentrations of organic acid, peroxodisulphate and mercuric chloride, lead to the conclusion that such induced reactions are governed by chain mechanism in which radical ion chain carriers participate.

Investigations revealed that the induced reduction of mercuric chloride by organic acids was mainly dependent on the acid-inductor reaction mechanism. Hence such reactions were investigated from the following two distinct but related aspects : (a) Kinetics and mechanism of the reaction between different acids and the inductor potassium peroxodisulphate, and, (b) kinetics and mechanism of the reduction of mercuric chloride by organic acids induced by potassium peroxodisulphate.

Acid-Inductor Reaction

Peroxodisulphate ion is a strong two-electron oxidising agent and majority of its reaction are believed to be initiated by,

$$S_2O_8^{2-} \longrightarrow S_2O_8^{2-*} \longrightarrow 2SO_4^{-}$$

which is in accord with the experimental evidence. The highly reactive sulphate radical-ions act as chain carriers to control the mechanism of the process of oxidation.

Kinetic investigations on the uncatalysed reaction between peroxodisulphate and the organic acids, reveal that the singular features of $S_2O_8^{2-}$

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[1] Summary of thesis on which Ph. D. degree has been awarded by this University.

* Activated.

-involved reactions are largely reproduced. The observed rate law in most of the cases, is

$$-\frac{dC_{S_2O_8^{2-}}}{dt} = k\, C^{x}_{S_2O_8^{2-}} \quad C^{y}_{\text{Acid}}$$

where $x=1$ and $y=0$ (or fractional). This rate law is valid for the investigated range of temperature, 45°-70°C, and over a 5-10 fold range of the initial concentrations of the reactants. Exceptions are there; for maleic acid-$S_2O_8^{2-}$ reactions, the rate is observed to be proportional to $(\text{acid})_0^{0\cdot5}$ for higher concentrations of maleic acid, and in the malic acid-peroxodisulphate reaction, increase of temperature results in the variation of order, when it is found to progress bimolecularly in the beginning and unimolecularly till completion.

For all reactions, the effect of temperature on 'k' over a range of 20-25° has been studied and the values for temperature coefficient, energy of activation and entropy of activation have been determined. The Arrhenius plot in each case has been found to be linear, giving :

$k_1=2{\cdot}280\times10^{11}$ exp. $(-21{\cdot}20/RT)$ min^{-1} (for lactic acid)
$k_1=3{\cdot}914\times10^{11}$ exp. $(-22{\cdot}11/RT)$ min^{-1} (for malic acid)
$k_1=3{\cdot}357\times10^{16}$ exp. $(-16{\cdot}94/RT)$ min^{-1} (for maleic acid)
$k_1=3{\cdot}63\times10^{15}$ exp. $(-26{\cdot}07/RT)$ min^{-1} (for glycine)

Calculations of the activation parameters showed that these generally range within the limits given below :

Temperature Coefficient$=2{\cdot}50$ to $3{\cdot}69$
Energy of activation $=20{\cdot}32-30{\cdot}31$ Kcals.
Entropy of activation $=-5{\cdot}74$ to $-6{\cdot}80$ e.u.
(In the case of saturated acids)
But with unsaturated acid i. e., maleic acid, it is 30·31 e.u.

Except at very high ionic concentrations, the rate of the acid- $S_2O_8^{2-}$ reaction has been found to be insensitive to the changes in ionic strength. H^+ ion is found to accelerate the reaction and such behaviour seems reasonable, since the aqueous decomposition of peroxodisulphate is catalysed by H^+ ions.

Experiments conducted in oxygen, carbon dioxide and nitrogen atmospheres, by flushing the contents of the vessel with each of these gases separately, revealed that oxygen accelerates the uncatalysed oxidation of the organic acids by peroxodisulphate, while nitrogen and carbon dioxide inhibit it.

Such kinetic observations have been interpreted in terms of the most likely reaction mechanism leading to rate expression for the respective systems.

Induced Reduction of Mercuric Chloride

The kinetics of the $S_2O_8^{2-}$-induced reduction of mercuric chloride by organic acids (lactic, malic, maleic and glycine), have been studied separately, at various temperature and concentrations of the reactants. The induced reduction reaction is characterised by zones, the three distinct ones being: (1) period of induction, (2) auto-catalysis and (3) auto-inhibition. The reduction of mercuric chloride commences after an initial period of induction followed by auto-catalysis for a short period, whereafter the rate is observed to decrease continuously with time. These zones are found to be affected by variation in temperature and concentrations of the reactants. The period of induction falls with the increase of temperature and concentration of the reactants.

Kinetic measurements on the $S_2O_8^{2-}$ -induced reduction of mercuric chloride by lactic acid, revealed the reduction rate to be first order in lactic acid, mercuric chloride and peroxodisulphate in low concentration range. Beyond 0·2 M acid concentration a fractional order dependence was encountered, whereas at $S_2O_8^{2-}$ concentrations greater than approximately 0·03 M, the reduction rate was found to decrease. A tentative chain mechanism, based on the acid-inductor reaction mechanism, leads to the rate expression.

$$\frac{dC_{Hg_2Cl_2}}{dt} = \frac{K\, C_{S_2O_8^{2-}}\, C_{L^-}\, C_{Hg^{2+}}}{C_{O_2}\left(1 + \frac{k'\, C_{S_2O_8^{2-}}}{C_{O_2}}\right)}$$

which accounts for the rate law.

In many respects the induced reduction of mercuric chloride by malic acid resembles that of lactic acid, though the nature of the products and the absence of definite order make the reaction somewhat different. The reduction rate was observed to be independent of the acid concentration and first order in peroxodisulphate, but only upto an optimum concentration. The variation of rate with respect to mercuric chloride concentrations can be expressed as :

$$1/\text{rate} = 0{\cdot}41 \times 10^5 + 650/(Hg^{2+})$$

A chain mechanism leading to the rate equation given below :

$$\frac{dC_{Hg_2Cl_2}}{dt} = 2\, k_1\, C_{S_2O_8^{2-}}\, \frac{k_4\, C_{Hg^{2+}}}{k_3\, C_{S_2O_8^{2-}} + k_4 C_{Hg^{2+}}}$$

satisfies the appropriate kinetic measurements.

Induced reduction by maleic acid has been studied more particularly and kinetic measurements undertaken to ascertain the rate laws show :

$$1/\text{rate} = 0{\cdot}048 \times 10^6 + 8653/(\text{Maleic Ac})_0$$
$$1/\text{rate} = 0{\cdot}051 \times 10^6 + 1620/(Hg^{2+})_0$$
$$1/\text{rate} = 0{\cdot}06 \times 10^6 + 1460/(K_2S_2O_8)_0$$

The proposed chain scheme, based on $S_2O_8^{2-}$ -maleic acid reaction mechanism leads to the rather complicated rate equation :

$$\frac{dC_{Hg_2Cl_2}}{dt} = \frac{2k_6k_1k_3\, C_{S_2O_8^{2-}}\, C_{M^{2-}}\, C_{Hg^{2+}}}{k'_2\, k_5 C_{S_2O_8^{2-}} + k'_2\, k_6 C_{Hg^{2+}} + k_6k_3 C_{Hg^{2+}} C_{M^{2-}}}$$

The reaction scheme and the rate equation derived therefrom, accounts for the kinetic data.

Mercuric chloride was not reduced by $S_2O_8^{2-}$ -glycine system, but addition of Cu^{2+} activated the acid to reduce it. Except for the addition of Cu^{2+} ions, the kinetics of induced reduction was sufficiently similar to that of other acids, indicating that a similar mechanism was operative. A general reduction scheme involving Cu(II) complex formation accounts for the kinetic characteristics.

Investigations have shown that carbon dioxide and nitrogen exert an accelerating influence on the rate of reduction, while the effect of oxygen is the reverse. The reduction is not favoured at low pH, as evidenced by the inhibiting influence of hydrochloric and sulphuric acids. Sodium acetate accelerates the reactions while other salts e.g., potassium chloride, potassium sulphate etc. exert specific ion effect.

Variations in the physico-chemical properties such as conductivity and pH, during the course of these reactions, have also been studied. Results obtained supplement the conclusions derived from the kinetic data.

A comparative study of the $S_2O_8^{2-}$ induced reduction of mercuric chloride by organic acid having different substituent groups reveals that though the principal mechanistic steps in all the cases are almost identical, the reduction being attributed to CO_2^- radical, the transient $S_2O_8^{2-}$ —oxidation steps differ, depending upon the organic acid employed. It has been further observed that the rate of reduction is a more significant function of the substituent in the acid molecule. Addition of ^-OH, $^-NH_2$ in the acid molecule increases the reduction rate while the reverse is true for the substitution of CH_2 and COOH.

The reduction of mercuric chloride by organic acids under the inductive influence of oxidising agents, such as $KMnO_4$, $K_2S_2O_8$ etc., has been explained as due to formic acid, formed as an intermediate product. But I have concluded from my experimental observations that though formic acid may be formed (for which a probable mechanism has been suggested), the reduction is mainly brought about by CO_2^- radical ($Hg^{2+}+CO_2^-=Hg^++CO_2$).

Thus, of the many important results that have emerged as a result of these investigations, the two most important are :

(1) that the rate of induced reduction of mercuric chloride is a more significant function of the substituent in the acid molecule, and

(2) to the free radical CO_2^- is ascribed the responsibility for the induced reduction of mercuric chloride.

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STUDIES ON SOME DIAGNOSTIC ASPECTS OF NEPHRITIS IN CANINES AND A NOTE ON DIFFERENTIAL LEUCOCYTE COUNT IN DOMESTIC FOWL*

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The purpose of the present investigation was to report on the clinical studies on two important types of experimental nephritis in dogs—nephritis due to chemical agents and nephritis of immune-origin. The study includes biochemical changes in urine and blood, haematological changes and demonstration of invivo localization of antikidney antibodies with the help of fluorescent antibody technique (FAT). An attempt has also been made to demonstrate as to which part of the kidney viz. cortex, cortex-medulla Junction or medulla is more nephrotoxic. An inquiry into the antigenic relationship of kidney to other organs of the host was also made.

Twentythree young, healthy mongrel dogs were used in the present study. Nephritis by chemical agent was induced by injecting 0·5 ml. of ol. terebinth diluted with 4 ml. of saline into each renal artery of experimental dogs No. 1-5. Immune nephritis was produced by intravenously injecting Rabbit antidog kidney cortex serum in dog No. 10 and 11, Rabbit antidog kidney cortex-medulla junction serum in dog No. 9 and Rabbit antidog kidney medulla serum in dog No. 12.

The clinical symptoms observed in chemically produced nephritis were listlessness, anorexia, nausea, retching, vomiting, dehydration, constipation followed by diarrhoea, pain at back, arched back, stiff-gait, subnormal temperature, weak pulse, intermittent, deep, slow, respirations, uraemic smell from breath, anaemia, proteinurea, haematuria, casts in urine sediment, reduced pack-cell volume (PCV), haemoglobin and total erythrocyte count (TEC), an increase in blood urea nitrogen (BUN) and blood creatinine. There were fibrillary contractions, stiffness of limbs and neck followed by unconsciousness and death.

On post-mortem of these dogs (No. 1-5) it was observed that spleen was contracted and there were necrotizing and ulcerative lesions in intestine and the ingesta was tarry. Pericaditis, congestion of lungs and brain oedema was also observed. Kidneys were enlarged and capsule was tense. On histopathological examination of the kidney of all the dogs (No. 1-5), massive necrosis of proximal and distal convoluted tubules was observed. Some of the glomeruli were also damaged and there were intertubular haemorrhages. Casts were also found in tubular lumen.

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* This is an abstract of the thesis submitted in partial fulfilment of the requirement for the degree of M.V.Sc. in Medicine of the Agra University, in the year 1968.

Dog No. 9 developed severe nephritis. Symptoms like proteinuria, haematuria and casts were seen following injection. No appreciable change was found in haemogram. ESR was increased. Leucogram showed leucocytosis accompanied by lymphocytosis. BUN and Blood creatinine were elevated.

In dog No. 10 and 11, proteinuria, haematuria and casts were seen. These dogs became anaemic in the beginning but gradually recovered. An increase in ESR and TLC with lymphocytosis was observed. BUN and blood creatinine values were not so high as in the dog No. 9.

Dog No. 12 showed only transitory abnormal urinary findings. There was no appreciable rise in BUN and blood creatinine. Haemogram values were low in the beginning of the experiment but became normal later on. Leucocytosis with lymphocytosis was observed.

Control dogs, in which normal rabbit serum was injected, apparently showed no change except increased leucocyte count with slight lymphocytosis.

On post-mortem of dog No. 9,10,11 and 12, no abnormal signs were seen except an enlarged spleen and slightly enlarged kidneys. In control dogs only spleen was found enlarged while kidneys were normal.

On histopathological examination major alterations were found in dog No. 9. These changes were confined to the glomeruli in general and tubules were involved to a lesser extent. In control dogs no such change was seen.

With FAT a bright, apple green fluorescence was seen in the glomeruli, tubules, bowman's capsule and intertubular capillaries of dog No. 9,10 and 12. It appears that glomeruli are the seat of fixation for antibodies in immune nephritis.

In double gel-diffusion test, with rabbit antidog kidney serum and antigens prepared from various organs of dog, 6 precipitin lines were obtained with kidney cortex, 7 with kidney cortex-medulla junction, 3 each with kidney medulla, liver, spleen, lung and one with muscle antigen. No precipitin bands were seen with trachea, heart and brain. The possible antigenic relationship of these organs seems to be. However, further work is indicated to define the antigenic make-up of each tissue more precisely.

During the course of this investigation a side project was also worked upon to establish the normal differential leucocyte count in different breeds of poultry viz. Rhode island red (R.I.R.), Whiteleghorn (WL), New hampshire (N.H.), Blackminorca (B.M.) and White cornish (W.C.).

The percentage mean values of heterophils with their standard deviation were observed as 35·87±9·42; 33·3±4·27; 27·1±7·57; 28·49±1·4; 26·7±5·57; 29·9±6·4; 27·2±9·1 for R.I.R. male, R.I.R. female, WL male, W.L. female, N.H. female, B.M. female and W.C. female respectively.

The average percentage values of Eosinophils with their standard deviation were found to be 2·8±0·71 for R.I.R. male; 1·6±0·72 for R.I.R. female; 1·88±0·62 for W.L. male; 1·95±0·75 for W.L. female; 2·66±0·97 for N.H. female; 2·88±1·66 for B.M. female and 2·5±1·1 for W.C. female.

The percentage mean values of Basophils with their standard deviations were found to be 2·5±0·72; 2·2±0·99; 2·5±0·83; 2·17±0·80; 2·05±0·76; 3·0±0·86; 2·5±0·86 for R.I.R. male, R.I.R. female, W.L. male, W.L. female, N.H. female, B.M. female and W.C. female respectively.

The average percentage values of lymphocytes with their standard deviation were found to be 52·46±10·77 for R.I.R. male; 58·10±9·33 for R.I.R. female; 62·2±8·18 for W.L. male; 62·0±4·05 for W.L. female; 62·8±5·32 for N.H. female; 58·6±8·10 for B.M. female; 62·4±9·33 for W.C. female.

The average percentage values of monocytes with their standard deviation were found to be 6·4±4·18; 4·63±1·6; 6·27±1·83; 5·37±1·67; 5·66±1·72; 5·77±1·9; 5·20±2·48 for R.I.R. male, R.I.R. female, W.L. male, W.L. female, N.H. female, B.M. female and W.C. female respectively.

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SEROLOGICAL STUDIES OF THE FRACTIONS OF *BRUCELLA ABORTUS* AND SOME SEROLOGICAL REACTIONS IN EXPERIMENTAL BRUCELLOSIS[1]

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This investigation attempts to study antibrucellacidal substances of *Brucella abortus* organisms, brucellacidal activity of the healthy, infected and vaccinated calf sera and the application of haemagglutination, complement fixation and agglutination tests for the precise diagnosis of bovine brucellosis. The chemical extracts were qualitatively analysed for protein, polysaccharide, ribonucleic acid and deoxyribonucleic acid. The complement fixation test was standardized, using 2 units of guinea pig complement, 2 units of haemolysin and 4 units of *B. abortus* S99 plain agglutination antigen. Amongst various chemical extracts, the sodium chloride and trichloroacetic acid extracts, could only sensitize sheep erythrocytes but not bovine erythrocytes. Agglutination test was carried out as recommended by FAO/WHO using *B. abortus* plain agglutination antigen. The antisera, collected from calves which were inoculated with *B. abortus* Strains 544, 19, *B. abortus* S99 acetone dried cells, sodium chloride and alkali extracts and of hill bulls, which were inoculated with tryptic digest residue (crude cell wall like substance), were used for the serological response. Antibrucellacidal activity of the extracts was tested with healthy bovine sera. A comparative study of the brucellacidal activity of healthy, infected and immune calf sera was also included.

A study of the correlation of complement fixing antibodies and agglutinins has indicated that both these appeared at the same time, on 6th day in calves infected with *B. abortus* S544. Agglutinins appeared earlier, on 3rd day and complement fixing antibodies started appearing on 7th day in calves vaccinated with strain 19 and tryptic digest residue (crude cell wall like substance). Complement fixing antibodies appeared on 6th day in calves vaccinated with acetone dried cells but agglutinins appeared on 3rd day. The complement fixing antibodies disappeared earlier in vaccinated group of animals than in the infected ones. The complement fixation titre was negative on 90th day in vaccinated group of animals and it was still present in the infected ones. The sodium chloride extract and the alkali extract induced low agglutinin but high complement fixing antibody response, although both were transient. The tryptic digest residue (crude cell wall like substance) elicited high agglutination but very low complement fixation titre. These results have reveald that the agglutinin response was low and steady in the infected group of animals but was high and declined soon in the vaccinated ones. In comparison with the agglutinin response, complement fixing antibody response was higher in the infected group of animals than that in the vaccinated group. Simultaneous performance of the complement fixation and agglutination tests, therefore, would appear to be necessary to differenciate between infection and vaccinal titres in bovine brucellosis.

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[1] This is an abstract of the thesis submitted and approved for the award of M.V.Sc. degree in Bacteriology, 1965.

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An assessment of the haemagglutinating activity of the extracts was carried out, using sheep and bovine erythrocytes and antisera prepared in rabbits against live organisms and suspension containing sodium chloride, alkali and tryptic digest extracts and tryptic digest residue with or without saline in oil emulsion as adjuvant. Sera collected from bull calves which were inoculated with acetone dried cells, sodium chloride and alkali extracts were also tested for this activity. None of the extracts as such, could sensitize sheep or bovine erythrocytes. The sodium chloride and trichloroacetic acid extracts after alkali treatment, could sensitize only sheep erythrocytes. The sodium chloride and trichloroacetic acid extracts after alkali treatment, the alkali extracts from sodium chloride extracted residue and the alkali extract sensitized cells showed haemagglutination with the antisera prepared in rabbits against suspension containing extracts and residues of *B. abortus* S99. The antiserum against the sodium chloride extract showed haemagglutination test positive with sheep erythrocytes treated with the sodium chloride extract as such, and after alkali treatment, but it was negative with the alkali extract from the sodium chloride extracted residue because of absence of surface antigens. It was positive with the trichloroacetic acid extract after alkali treatment and alkali extract. The calf antisera, against alkali extract and acetone dried cells showed haemagglutination with the alkali extract and alkali treated sodium chloride and trichloroacetic acid extracts. The test was also positive (titre 1:32), when the antiserum against alkali extract from sodium chloride extracted residue was used. These results indicate that both the surface and the deeper antigens are involved in the indirect haemagglutination test, and alkali treated extracts are absorbed better on the sheep erythrocytes. It was noticed that haemagglutinins disappeared much earlier in vaccinated animals than infected ones showing a definite correlation with agglutinins and complement fixing antibodies. It was, therefore, suggested that indirect haemagglutination and agglutination tests, if carried out simultaneously would prove useful to differentiate vaccinal from infection titres.

The study of the antibrucellacidal activity of the various fractions has revealed that the tryptic digest residue (crude cell wall like substance) possessed very high activity as compared to other extracts and acetone dried cells. It would be seen that the unextractable residue, probably composed of cell wall fraction, possessed the maximum antibrucellacidal activity. It was, interesting to note that neither proteins nor polysaccharides possessed high antibrucellacidal activity but a combination of both exhibited a considerably higher degree of activity. The deeper antigens possessed poor neutralizing power because alkali extract from sodium chloride extracted residue was found to have very poor activity. A comparative study of the brucellacidal activity of healthy, immune and infected bovine sera has revealed no significant difference in the activity of immune and infected sera while the healthy serum showed a significantly high activity.

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STUDIES ON THE ANATOMY AND HISTOLOGY OF THE DIGESTIVE SYSTEM IN RUMINANT—*BOS BUBALIS* L.[1]

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The remarkable ability of ruminants in refining coarse roughages into rich and protective human foods and articles of commerce, which has attracted the attention of great many Scientists throughout the world, tempted the author to investigate buffalo (*Bos bubalis* L.) for its digestive system to know if its fascinating ability of converting the poor quality roughages into rich bovine milk could somehow be related to its structure and development. Consequently, the investigation "Structure and Histology of the digestive system in ruminant", using buffalo as the subject was instituted in two parts as under:

Part A—It is primarily devoted to the anatomical and histological aspects of the adult digestive system and embraces the observations on 25 adult animals. In addition to the morphological and histological descriptions of different parts, their detailed linear, weight and capacity measurements have also been recorded in relation to body size, body weight, total digestive tract and part thereof as and when needed. The disposition of inner mucosa of the various stomach compartments has been specially attended to and the variety of patterns come across have been put on record. For the minute details, histological preparations have also been made use of.

Part B—It deals with the development of digestive system and is planned to know the exact nature and origin of the forestomach compartments, viz., rumen, reticulum and omasum and the pattern of their development during pre- and post-natal growth. In addition to the compound stomach developmental details of intestines and accessory digestive glands have also been taken into account. The observations contained in this part are based on 150 foetuses and 35 calves of different ages. The highlights of the findings are as under :

The mouth of buffalo is broadly muzzled and is provided with powerful jaws for the efficient grinding of food. The buccal cavity is quite capacious and has many buccal glands that pour lot of mucus into the oral cavity.

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[1] This is an abstract of the thesis submitted to and approved by the Agra University for the degree of Doctor of Philosophy.
Contribution No. A.H. & D. 133/R 82/AS 51.

Like that of cow, it has ridged and raphed hard palate, heterodont, thecodont and hypsodont teeth and rasp like tongue. The crowns of molars and premolars have extra large grinding surfaces and are quite well enamelled and cemented. The tongue has filliform, fugiform and circumvallate papillae of which the last two are provided with taste buds. The three pairs of salivary glands, viz., parotid, mandibular and sublingual that also pour their secretions into the mouth are of albuminous and/or mucous type.

The pharynx, which is short and narrow, has poorly developed tonsils. It leads into the oesophagus which lacks a peritoneal covering and is provided with two sets of striated muscles which cross each other obliquely to start with, getting spirally oriented and finally forming the inner circular and the outer longitudinal sets at the cardia. It has no oesophageal glands and like that of cow its epithelium is covered with a thick layer of stratified squamous cells.

The stomach of buffalo, as per cent of body, weighs heavier than that of cow and is quite capacious. Rumen alone accounts for over 88 per cent of the total stomach capacity and contains about 5-10 per cent more ingesta than that of cow. The tissue weights of reticulo-rumen also weigh about 15 per cent more than that of cow as against omasum and abomasum which weigh comparatively lighter.

The omasum in buffalo has comparatively lower tissue weight, lesser ingesta and restricted capacity than that reported for cow but has almost the same number of laminae as cow. This probably leads to narrower inter-laminar spaces with thin films of ingesta between them for a more efficient and effective absorption.

The mucosa of forestomachs has a dark brown colour and is disposed to have papillated, ribbed and laminated form in the rumen, reticulum and omasum respectively. The rumen papillae have a reciprocal relationship in respect of size and number. They are more elaborately developed in the anterior regions and are more densely populated in the posterior ones.

Histologically, the mucosa of rumen, reticulum and omasum are covered with a layer of stratified squamous epithelium with keratinised top line. Of this, the basal layer gets numerously folded into the squamous layer and gives rise to the papillary bodies with a lamina-propria core, presumably containing the absorptive element of the mucosa. The formation of papillary bodies, therefore, seems to be of great functional importance, firstly because their formation reduces the distance between the mucosal surface and the presumed absorptive sites in the lamina-propria and secondly their development increases the absorptive surface considerably. It also appears likely that, as compared to cow, the total thickness of the squamous epithelium is low in case of buffalo. The lamina-propria blends with the subjacent submucosa for want of muscularis mucosae in case of rumen and reticulum as against the omasum which develop in between them.

The mucosa of the oesophageal groove resembles that of rumen in the dorsal part and that of reticulum in the ventral where it runs into the omasal neck to the omasal groove. In omasal neck it is provided with prominent folds studded with unguliform papillae. These helped by the sphincter muscle at the reticulo-omasal orifice make a functional sieve which does not permit larger food particles to enter the omasum.

The functional significance of omasum is due to its forward and rotational movements it makes which help the liquid food fraction enter the abomasum quickly through the omasal groove along the lesser curvature while the solid fraction of the food fills the organ in between the laminae in thin films and traverses the organ slowly. A differential passage of liquid and solid food, therefore, occurs through the omasum.

Absomasum, the glandular portion of stomach, has well marked fundic and pyloric glands in its mucosa as against the rumen reticulum and omasum which have no glandular structures in their mucosa.

The stratified squamous lining of the forestomachs with keratinized border, is to be viewed as a special adaptation in response to the rough nature of food, which they have become used to, during the course of their evolutionary process. The squamous cell layers thus protect the delicate parts of the intima of the forestomach compartments from the ill effects of the rough texture of food and at the same time permit a free diffusion of food metabolites through its body.

The intestines of buffalo measure about 40 meters as against 50 meters or more of cow. This works out roughly to about 27 : 1 intestine to body (pin-shoulder) length. Amongst the different segments the longest small intestine is followed by colon, rectum and caecum. The different regions of the small and large intestines merge imperceptibly with each other except at the ileo-caeco-colic junction where the three segments are marked distinctly. The caecum in case of buffalo measured smaller than that of cow.

Histologically, intestinal villi are found throughout the length of small intestine right from duodenum, down to ileum. They are numerous and smaller in duodenum, and comparatively fewer and longer towards ileum. The villi are altogether wanting in the segments of large intestine where the inner mucosa is variously disposed into ridges and furrows.

The inner mucosa of the intestine as a whole, is provided with goblet and absorptive cells. Of these the goblet cells are fewer in the proximal portions of the intestine and progressively increase towards their distal end. All the segments of the intestine, however, share simple intestinal glands in common. The duodenum, in addition, has the duodenal glands (Brunner's glands) of the recemose type in its submucosa, which in other regions and segments is devoid of any such gland.

The nature and distribution of the gut contents as a whole indicate that rumen gets the largest share and is followed by omasum, small intestine, colon, rectum, abomasum, reticulum and caecum in descending order. Of all the segments, omasal contents have the maximum dry matter as against the lowest of the small intestine.

The liver and pancreas make 1·27 and 0·07 per cent of the empty body and 20·79 and 1·11 per cent of the empty digestive tract by their tissue weight. Histologically, the liver has poorly developed stroma, as such, the interlobular connective tissue partitions are not well developed. Each hepatic lobule is composed of a large number of irregular anastomosing plates of liver cells arranged more or less radially around a central venule. These are separated from one another by the hepatic sinusoids that also persue a radial course and connect the interlobular portal venules with the intralobular central venule leading ultimately to the hepatic veins. The bile canaliculae that lie between the liver cell plates also run radially to join the bile ductules in the interlobular connective tissue.

The pancreatic parenchyma, on the other hand, has both exo- and endocrine portions. The lobes and lobules of the exocrine portion are separated by the connective tissue but their acini have only the reticular cell partitions between them. The endocrine portion "Islets of Langerhans", on the other hand, appear to be less numerously scattered than described for other animals. This may be because the utilization of glucose at tissue level is of much less importance in this animal. The endocrine portions are completely separated from the exocrine acini by a membrane and their cells are comparatively much smaller and packed in a compact mass. A careful examination of these cells reveals that they contain two or more types of cells.

The innervation pattern of the stomach compartments is suggestive of the fact that the complex movements of the stomach compartments are primarily under the control of the central nervous system through its vagal supply and the sympathetic part is of much less importance. It further appears that the directness of the vagal innervation varies considerably. It is more direct in the anterior part of the rumen, body of the reticulum, region surrounding the oesophageal groove down to the omasal neck, omasal pillar and the lesser curvature of the abomasum. The supply of major blood vessels to the various compartments of stomach and segments of the intestine, have almost the identical plan with that of cattle.

The developmental aspects of the digestive system in buffalo indicate that the roof of the buccal cavity is derived from the transpalatine processes of the maxilla while its floor is contributed by the first pair of viecera arches of the embryo. Other associated structures develop as evaginations of the oral cavity. Cheeck papillae and the ossified gum cores develop towards the close of the foetal life. The tongue elaborates with the growing snout and the different kinds of papillae also develop towards the close of gestation.

The oesophagus which is represented by a short wide membraneous tube in the beginning grows in length with the straightening of the foetal posture and neck. The basal cells of the mucosal epithelium have cuboidal shape with oval nuclei and are covered with a single layer of squamous cells in the beginning. These grow in number with the age of foetus and develop a keratinized border at the close of foetal term. The oesophageal groove along with its two lips, is also laid down quite early in life. It develops and elaborates from the invaginating reticular walls and the concentration of the muscle fibres into them with the growth of the foetus and by about the full term it is completely formed.

The relative development and the dispositional shifts, which the stomach compartments make during the pre- and postnatal growth, are quite interesting. The heaviest rumen at 3rd month of foetal age, followed by abomasum, omasum and reticulum, are seen changing and reversing their relative tissue weight positions several times with each other both during pre- and postnatal growth. The reticulum, however, abstains from these changes and uniformly maintains the lowest position althrough. Almost a similar trend is exhibited by them in respect of capacity also. At birth rumen, reticulum and omasum combinedly are smaller than the abomasum but these compartments develop more rapidly when the calf takes to roughage eating.

During very early stage of foetal growth all the four stomach compartments, some of which may not even be clearly marked out, lie in a cradiocaudal straight line. Sometime during the 3rd month of foetal life, the different compartments start reorienting themselves with regard to their relative positions as a result of differential growth and their straight continuity is lost. Finally the stomach complex turns clockwise through 90° on its longitudinal axis and then rotates on its transverse one at the point of oesophageal attachment to 180° so that its transverse axis, which was almost horizontal to start with, gets vertically directed and the original longitudinal axis is completely reversed and by the 4th month of gestation the different compartments get topographically reoriented.

At birth and during the absolute milk feeding regime of the calf the abomasum also lies almost on the left side of the median plane in the abdominal cavity. As the forestomachs start gaining importance with the ingestion of roughages the abomasum moves away from the diaphragm caudally and to the right to attain the final position by about the 4th or 5th month of postnatal life when the calf starts eating large quantities of roughages.

The rumen papillae and the reticular ribs are seen growing from 8th month of gestational life of the calf and get quite numerously disposed by the full term. After birth the papillae continue to grow in size, elaborate in form and develop papillary bodies as the calf takes to roughage eating. The colour of the mucosa of forestomachs, which is generally pale-white at birth, changes through various shades of yellow and brown to dark brown in colour depending upon the milk feeding regime and its transition to the roughage eating one.

Histologically, the walls of the different stomach compartments have the blue prints of all the layers true of an adult during the early development which progressively elaborate with the growth of foetus and calf. The squamous cell layers which line the forestomach compartments from within are simple and fewer during the earlier stages, grow to get numerous by about the close of gestational life and start receding back again after the calf is born and starts taking roughage. Elaboration of the papillary bodies also appears to take place under the influence of roughage consumption and V.F.A. production.

The intestine grows from a humble beginning. A major portion of the small intestine is added during the first half of the foetal life after which their growth rate declines. Its length in proportion to colon shows an interesting feature. It varies from 2:1 during second month of intra-uterine life through 10:1 during the 4th month of foetal life, 6:1 at birth to 4:1 in an adult. It, therefore, appears that the small intestine elaborates more during the foetal life, as against the large one, which does, after the calf is born.

In the newly born calf the intestines are primarily situated in the left half of the abdominal cavity from where they move to the epigastric zone on the right side due to the extensive growth of the rumen on the left. The coils of the colon which remain cylindrical during the earlier stages of calf growth change through discoidal to flattened condition with the growth of calf and its taking to roughage diet.

Histologically also, the intestines have a simple start but have all the basic layers in their structure even during the early part of their foetal development except the colon which lacks a peritoneal covering because of its development between the mesenteric layers supporting the small intestine. As in other organs, the lamina-propria and the submucosa of intestine also remain merging and indistinguishable from each other for want of a defined muscularis mucosae in the beginning, which develops later and the submucosa develops Brunner's glands in the region of duodenum also.

The Mucosa which remains almost similar in the different segments of the intestine to start with gets differentiated as villiated of the small intestine, smooth of the caecum and colon and ridged of the colon and rectum. They, however, develop the intestinal glands in common with the growth of foetus.

The distribution of ingesta in the different compartments of stomach and segments of the intestine through post-natal stages presents an interesting feature. During the early milk feeding regime the small intestine has the maximum contents and is followed by abomasum, rectum and colon in descending succession while the other stomach compartments and caecum contain only nominal amounts. But as the calf grows the rumen starts gaining contents and the colon and rectum interchange their positions. Very soon rumen contents supercede those of the small intestine and continuously make fast gains at the cost of other compartments so much so that it holds about 80 per cent of the total gut contents at the age of about a year as against about 77 per cent of the adult.

Of the liver and pancreas, liver shows an extensive outgrowth even before the 40th day of embryonal life. As it grows it encloses the developing intestines within its mass alongwith the yolk stock. Its growth remains comparatively extensive during the early foetal life which gets retarded subsequently. Its close and intimate connections with the intestine gradually get unfastened leaving the bile duct as the sole remnant of this tie by the end of foetal term.

The dispositional changes of liver during the post-natal growth are again interesting. In a newly born calf it occupies a median position between the stomach and the disphragm and then gradually moves to the right due to the extensive growth of reticulo-rumen on the left side.

Pancreas on the other hand originates as bud-like structures developing in between the duodenal loop which subsequently grows and elaborates with the passage of time and growth of the foetus. It weighs proportionatly heavier during the milk feeding regime than that of the adult.

The observations described and discussed in the text present a vivid picture of structure and development of the digestive tract in buffalo and how it compares with whatever is available for cow in the literature. The illustrated details of the findings will be published in a series of papers in this research journal as below:

Studies on the digestive system of ruminants:

1. Development of Fore-gut and Compound Stomach in buffalo—*Bos bubalis* L.
2. Development of Intestine and Accessory Digestive glands in buffalo—*Bos bubalis* L.
3. Structure of the Fore-gut in buffalo—*Bos bubalis* L.
4. Structure of the Compound Stomach in buffalo—*Bos bubalis* L.
5. Structure of the Intestine in buffalo—*Bos bubalis* L.
6. Structure of the Liver and Pancreas in buffalo—*Bos bubalis* L.
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8. Innervation and Blood supply of the digestive system in buffalo—*Bos bubalis* L.

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THE LIFE HISTORY OF *CEYLONOCOTYLE SCOLIOCOELIUM* (FISCHOEDER, 1904) NASMARK, 1937—A COMMON AMPHISTOME PARASITE OF RUMINANTS IN INDIA

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Introduction

Ceylonocotyle scoliocoelium is a common amphistome found in the rumen of sheep, goats, buffaloes and cattle in India. A brief note on its life history has been published by Mukherjee (1962). During a survey of the incidence of amphistome infection in snails, three specimens of *Bulimus pulchellus* were found in September, 1965, in the suburb of Rithora, Bareilly (U. P.), to discharge *Cercaria bulimusi* Peter and Srivastava (1955). The cercaria on experimental infection to two clean kinds developed into *Ceylonocotyle scoliocoelium*. The complete life history of the parasite is described in this paper.

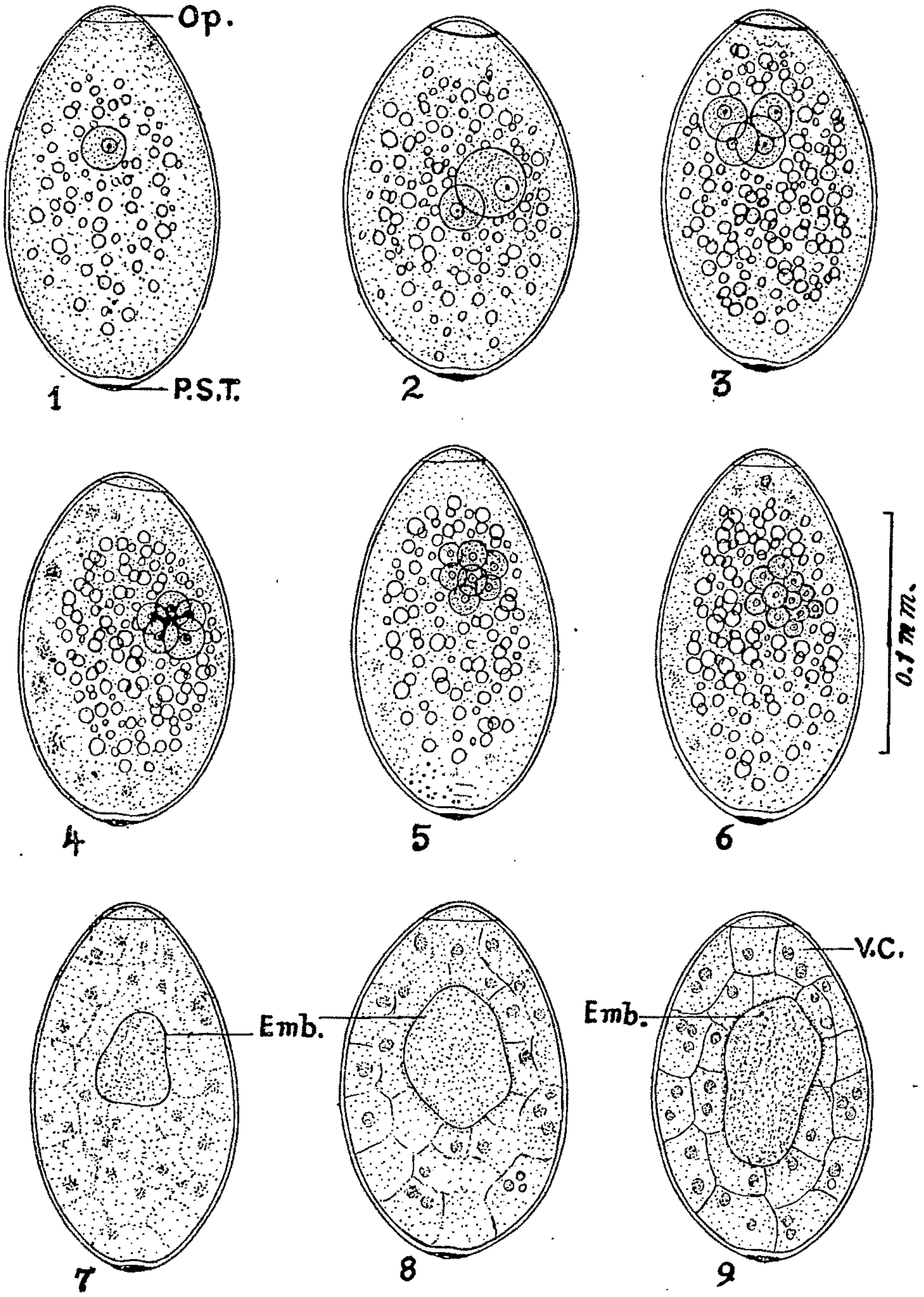
Egg

(Figs. 1-7)

The mature eggs of *C. scoliocoelium* voided in the faeces of the final host are light grey in colour and oval in shape. The posterior end is rounded with a small shell thickening. The shell is transparent and uniform in thickness except at the posterior end. The operculum is distinct unlike that in *G. bathycotyle*.

The yolk mass is composed of a large number of spherical yolk cells, each covered with an outer membrane and filled with translucent liquid containing clearly visible light-grey small suspended granules. A small ovum with indistinct outline is situated near about the centre, surrounded by the yolk cells. In the majority of eggs early segmentation, mostly four to sixteen celled stages, is observed at the time of deposition by the worms kept in petri dishes.

The eggs of *C. scoliocoelium* measure 0·135-0·155 mm. in length and 0·067-0·075 mm. in width. The average size of 100 freshly deposited eggs is 0·144 x 0·070 mm. The average diameter of the operculum is 0·02 mm. (0·016-0·023 mm.) and of the ovum 0·019 mm. (0·013-0·023 mm.)



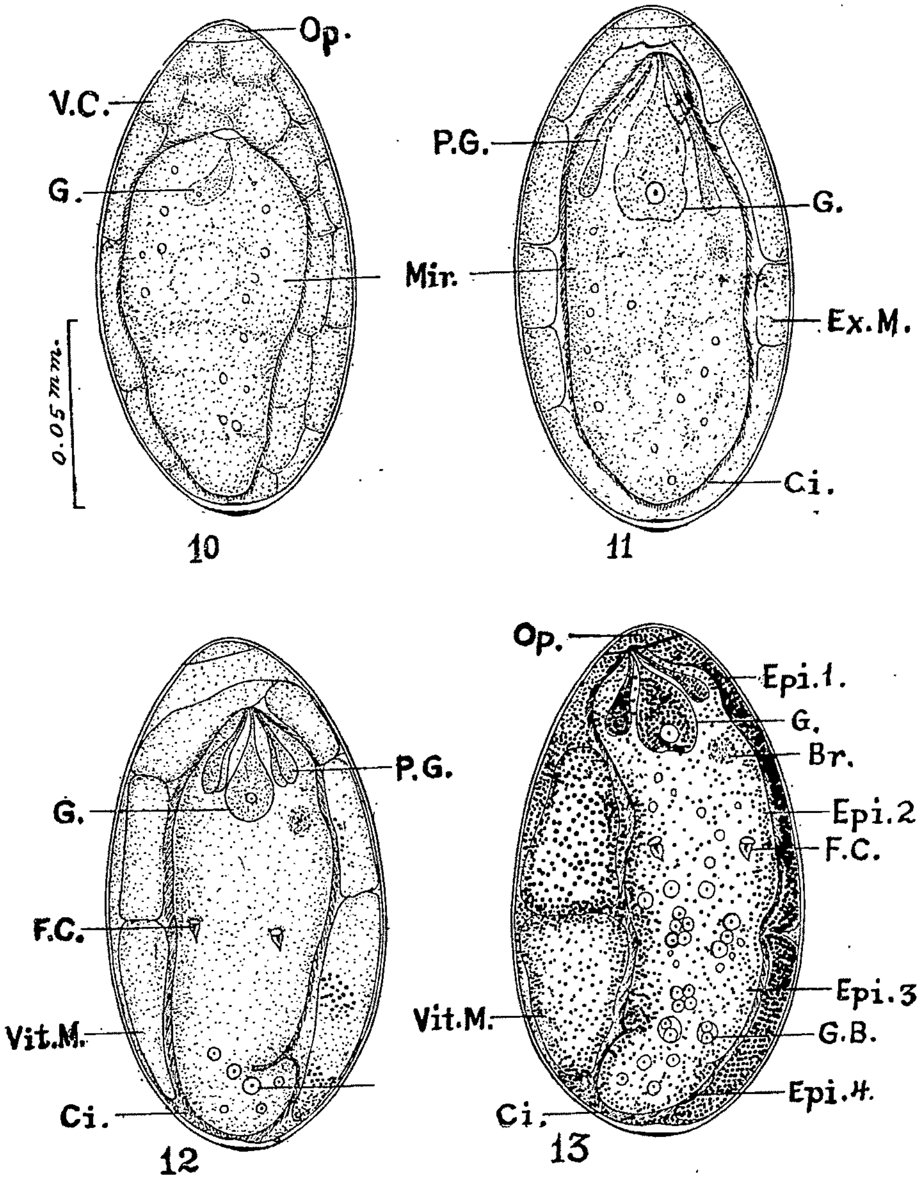
Eggs and developing miracidium of *Ceylonocotyle scoliocoelium*

Figs. 1—6 Fresh eggs deposited by adult worm.
Fig. 7 Freshly deposited egg with distinct embryo.
Figs. 8, 9 Eggs on the 3rd day of development.

DEVELOPMENT OF EGGS

(Figs. 1-13)

The development of the eggs of *C. scoliocoelium* has been studied in tap water and faeces in the laboratory at room temperature from June to August, 1966. During this period, the maximum temperature varied from 34·4 to 43·2°C



Developing miracidium of *Ceylonocotyle scoliocoelium.*

Fig. 10 Egg on the 6th day of development.
Fig. 11 Egg on the 9th day of development.
Fig. 12 Egg on the 11th day of development.
Fig. 13 Egg on the 12th day of development

and the minimum temperature ranged from 27° C to 27·7° C. The eggs of the parasite were obtained from a donor kid already infected experimentally with the cercaria of the parasite.

The miracidia hatches out of the eggs in water culture within eleven days in June and July. In August, they require twelve (11 to 13) days for their full development upto the miracidial stage. In faecal cultures, however, they take longer time for the development of the miracidia. In June and July the miracidia hatch out in 12 to 17 days, while in the month of August they take 17 to 18 days.

During the first three days, the embryos are in 4 to 16 celled stage. Their average size in freshly deposited eggs is 0·019 mm. (0·013-0·023 mm.) and on the third day its average size is 0·033 × 0·028 mm. (0·019-0·048 mm. × 0·019-0·038 mm.).

From four to six days, the embryo increases in size, measuring 0·063 mm. × 0·040 mm. At the end of 5th day, it loses its spherical shape and becomes elongated in appearance. The yolk material decreases considerably and the embryo is clearly visible within the yolk mass. The vitelline mass forms large cells and fills a good portion of the egg cavity. The ciliary and body movements are absent. Rudiments of the gut, flame cells and terebratorium, etc., are not seen at this stage.

The 9 day old embryo measures on an average 0·092 mm. × 0·046 mm. It shows thickenings at four places on each side of the body indicating the development of four tiers of epidermal plates. Slight development of the cilia is also observed at this stage. The embryo shows infrequent movements inside the egg shell. Two flame cells are visible on either side of the body, a little anterior to the junction of the second and third tiers of epidermal cells. Flickering movements of the flame cells are observed. Large vitelline cells surround the embryo.

The development of the embryo is rapid from the 10th to 12th day. It increases in size and fills up the entire length of the egg. The miracidium makes occasional but rapid movements within the egg shell. The maximum size of the miracidium on the 12th day is 0·135 mm. × 0·053 mm. In the fully developed miracidium the epithelial cells become indistinct. The cilia are developed all over the body and can be seen clearly. The vitelline cells are further reduced in number and lie close to the inner wall of the egg shell, pushing the miracidium to one side of the egg. They are transparent and without granules. The terebratorium and two pairs of penetration glands are fully developed. Germ cells and brain mass are visible. A sac-like primitive gut, filled with granular contents, is fully developed. Flame cells with flickering movements of their cilia are conspicuous. Majority of the miracidia hatch out in the morning hours. They start hatching after the 12th day of development and most of them hatch out by the 16th day. The hatching is accelerated in the presence of powerful light and also in sunlight. The miracidia are positively phototropic and thermotropic.

MIRACIDIUM

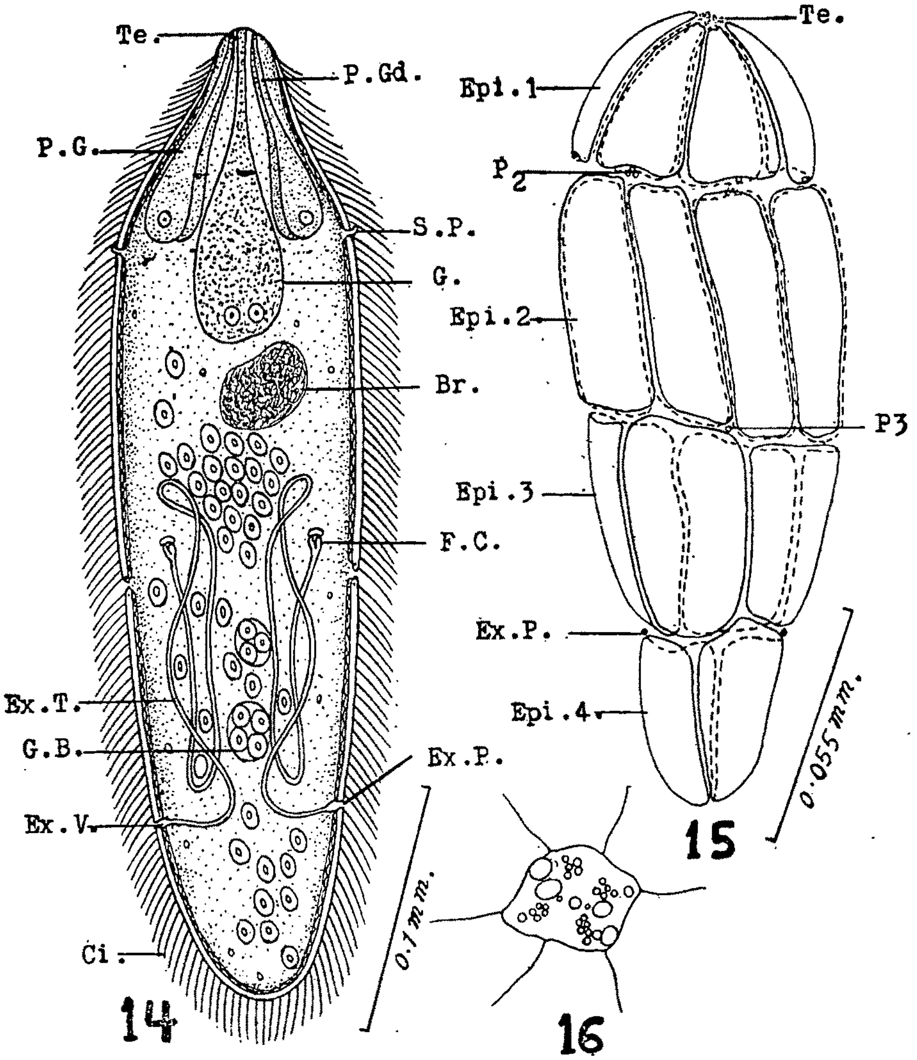
(Figs. 14-16)

The living miracidia measure 0·139–0·186 mm. × 0·040–0·069 mm. under coverslip pressure. The average of ten heat killed miracidia is 0·139 × 0·063 mm. (0·128–0·147 mm. × 0·053–0·071 mm.) and the average size of those killed with 1% formalin solution is 0·122 × 0·065 mm. (0·111–0·131 mm. × 0·059–0·068 mm.). The body of the miracidium, except the terebratorium, is covered with ciliated epidermal cells. They are 20 in number, arranged in four tiers, completely encircling the body. Their arrangement is: 6; 8; 4; 2 = 20. The cells of the first tier are broader than those of the other tiers. The average length of the cells of the first tier is 0·023 mm. (0·020–0·027 mm.). The cells of the second tier are rectangular, more elongated in shape with rounded corners and with maximum length of 0·048 mm. (0·045–0·050 mm.). The cells of the third tier measure 0·036 mm. (0·033–0·039 mm.) in length and are rectangular in shape and shorter than the cells of the second tier. The fourth tier covers the posterior end of the miracidium. Its cells are triangular in shape with the apex directed posteriorly. They are 0·023 mm. (0·021–0·026 mm.) in length. The nuclei in the cells of the second and third tiers are situated in the posterior part of the cells and are elongated in shape. The cilia of the miracidium are thick and interrupted at three places, i.e. at the junction of the four successive tiers. The cilia of the anterior part of the first tier are smaller and stiff, while those on the posterior part are longer. The cilia of the fourth tier are compactly arranged, directed posteriorly and are longer in length than those of the other tiers.

The sub-epithelium is a thin transparent layer, located under the ciliated epithelium. It extends from the posterior end of the miracidium to the anterior end and forms the terebratorium. It is exposed at the junction of the epidermal cells. The nuclei of this layer are irregularly distributed.

The first group of 26-28 papillae is present on the terebratorium and the second group, consisting of 10 small papillae, is situated at the base of the epithelial cells of first tier and at the junction of the first and second tiers. They can be represented in the formula 3; 3; 1; 1; 1; 1 = 10. Only two papillae are located in the space between the second and third tiers and are situated just opposite to each other. There are no papillae at the junction of the third and fourth tiers. Two excretory pores are located posteriorly, one each in the space between the two epidermal cells of the third tier.

The primitive gut is a flask-shaped structure, situated in the anterior quarter of the body. It is very prominent in the living miracidium and lies between the two pairs of penetration glands. When extended, it reaches upto the nerve mass. In the contracted condition it becomes broadened and occupies all the available space in the anterior fourth of the body. The narrow neck of the primitive gut opens at the base of the terebratorium. The nuclei of the gut are situated at its posterior end.



Miracidium of *Ceylonocotyle scoliocoelium*

Fig. 14 Anatomical features of the miracidium of *C. scoliocoelium.*
Fig. 15 Epithelial cells and papillae.
Fig. 16 Terebratorium. (Anterior view)

There are two pairs of penetration glands in the miracidium of *C. scoliocoelium*, one pair on each side of the gut. Each gland opens through a narrow duct on the terebratorium on the either side of the opening of the primitive gut. Its nucleus is situated at the posterior end. The penetration glands can be easily differentiated from the primitive gut by their small size and absence of granular contents. The brain mass is round to oval in shape and is situated posterior to the gut.

The excretory system consists of a pair of flame cells, situated laterally below the gut and slightly anterior to the junction of the second and third tiers of epithelial cells. Flame cell nuclei are not seen either in stained or unstained specimens. Each flame cell leads into an excretory duct, extending posteriorly. The duct makes a few coils just above the level of the excretory pore, turns on itself and opens into the excretory pore, situated between the third and fourth tiers of the epithelial cells. Just before opening into the excretory pore, it dilates into a small excretory bladder. The duct is of uniform thickness throughout its length.

The germ cells are scattered in the posterior two-thirds of the body, i.e. from the second to fourth tiers of epithelial cells. They are clearly visible in the specimens stained with intra-vital stains and can be easily differentiated from the sub-epithelium by their round contour with deeply stained nucleus and granular cytoplasm. They mostly occur in groups and appear as balls enclosed in a membrane and located in the area of the second and third tiers of epithelial cells. There are about 22 to 37 germ-cells, lying in the region of the fourth tier.

INTERMEDIATE SNAIL HOST

Clean laboratory bred young snails of various species were exposed to freshly hatched miracidia of *C. scoliocoelium*. The species of snails used were *Bulimus pulchellus*, *Lymnaea luteola*, *L. acuminata*, *Indoplanorbis exustus*, *Gyraulus convexiusculus*, *Helicorbis coenosus* and *Vivipara bengalensis*. Only *B. pulchellus* was found to take up the infection. Therefore, only laboratory bred young *B. pulchellus* were subsequently exposed to the freshly hatched miracidia of *C. scoliocoelium*.

INFECTION OF THE MIRACIDIUM INTO THE SNAIL

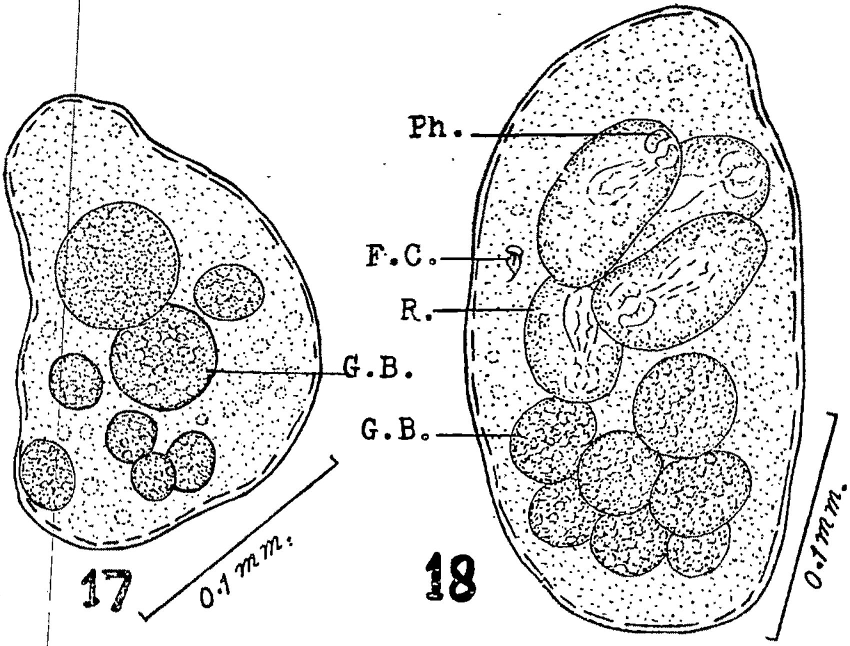
The snails were kept singly in small glass vials containing a small quantity of tap water and only 4 to 6 miracidia were introduced into each vial. Snails were given infection in morning hours as the miracidia hatched in large number in morning and were active for the following few hours.

SPOROCYST

(Figs. 17-18)

Infected *B. pulchellus* were dissected in normal saline every few days. On the eighth day of infection immature and mature sporocysts were recovered. They were studied in the living condition as such and also after staining with intra-vital stains.

The young sporocyst is egg-shaped with a central cavity. It has an average size of 0·109 × 0·058 mm. (0·094—0·117 mm. × 0·049—0·066 mm.). The cuticle is smooth, thin and transparent. The body-cavity contains small and large germ balls and a number of germ cells. The germ cells contain a granular material and are provided with a nucleus in the centre. The germ balls are rounded and stain more prominently with vital stains. The excretory system consists of two flame cells and their ducts.



Sporocysts of *Ceylonocotyle scoliocoelium*

Fig. 17 Young sporocyst.
Fig. 18 Mature sporocyst containing developed rediae.

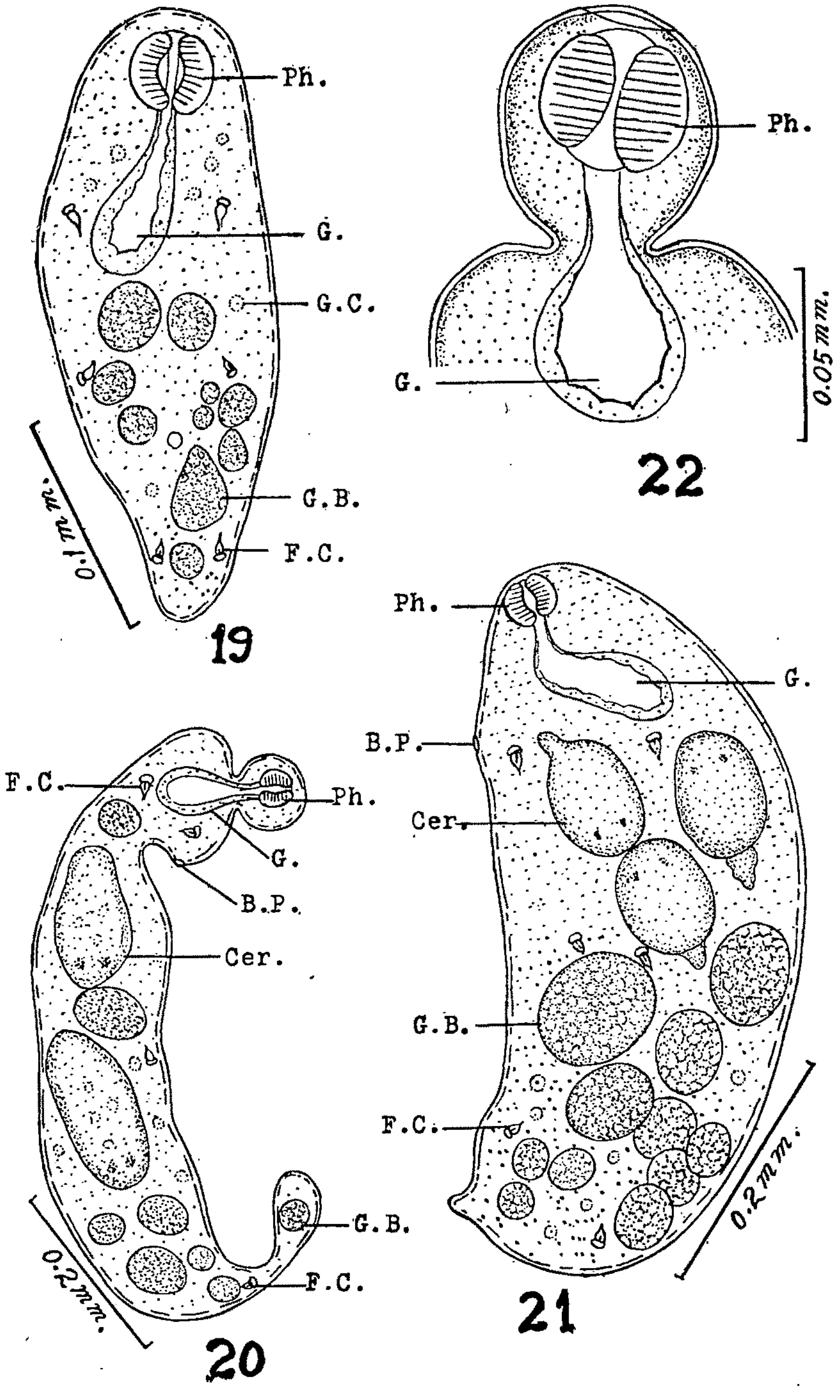
Mature sporocysts, containing developing rediae, were recovered only after twelve days of infection. Sporocysts at different stages of development were also recovered. They are covered with thin transparent cuticle and measure 0·16—0·175 mm. × 0·052—0·064 mm. The cuticle of the mature sporocyst is slightly thicker at both ends. The developing rediae are present at the anterior end of the sporocyst and possess a pharynx, a gut and primordial germ balls.

REDIA

(Figs. 19-22)

The redia of *C. scoliocoelium* is elongated with smoothly rounded anterior and posterior ends. The anterior part of the body is wider while the posterior part narrows gradually and ends bluntly. The rediae measure 0·571—0·70 mm. × 0·153—0·23 mm. No papillae are present at its anterior end.

The mouth is situated at the anterior end of the body and is followed by a muscular pharynx. The size of the pharynx varies according to the size of body. A small oesophagus originating from the posterior part of the pharynx leads into a well developed bag-like gut, measuring 0·105 mm. × 0·104 mm. The salivary glands are present on either side of the pharynx. Each gland consists of a large number of cells and is surrounded by a thin membrane. The gland is an elongated, lobe-like structure extending upto the anterior part of the gut.



Rediae of *Ceylonocotyle scoliocoelium*

Fig. 19 Young redia

Figs. 20,21 Mature rediae containing germ balls and developing cercariae.

Fig. 22 Anterior part of the redia, showing mouth, pharynx and gut.

There are three pairs of flame cells. One pair is situated in the anterior part at the level of the gut, another in the middle of the body, while the third pair, is in the posterior part of the redia. The flame cells on either side are connected by a long excretory duct of uniform thickness.

The germ balls of different sizes fill up the posterior part of the body cavity. They possess nuclei in the centre and are located anterior to the germ cells and contain granular mass. The mature redia contains a maximum number of four developing cercariae. The germ balls develop into cercariae which are whitish, oval-shaped structures with a small protuberance at their posterior end representing the developing tail. In the anterior part, two black points appear. The birth pore in the mature redia appears like a small projection. It is situated at a distance of about 0·15 mm. from the anterior end of the body.

CERCARIA

The developing cercaria is a small, transparent, whitish, ovoid body, provided with a short and broad tail and two small black lateral eyes at the anterior end. It has a small oral sucker, small oesophagus and cystogenous cells. The acetabulum and the partition between the tail and the body are yet not formed. The development of the other organs takes place in the tissue of the snail after the cercaria comes out of the redia.

IMMATURE CERCARIA

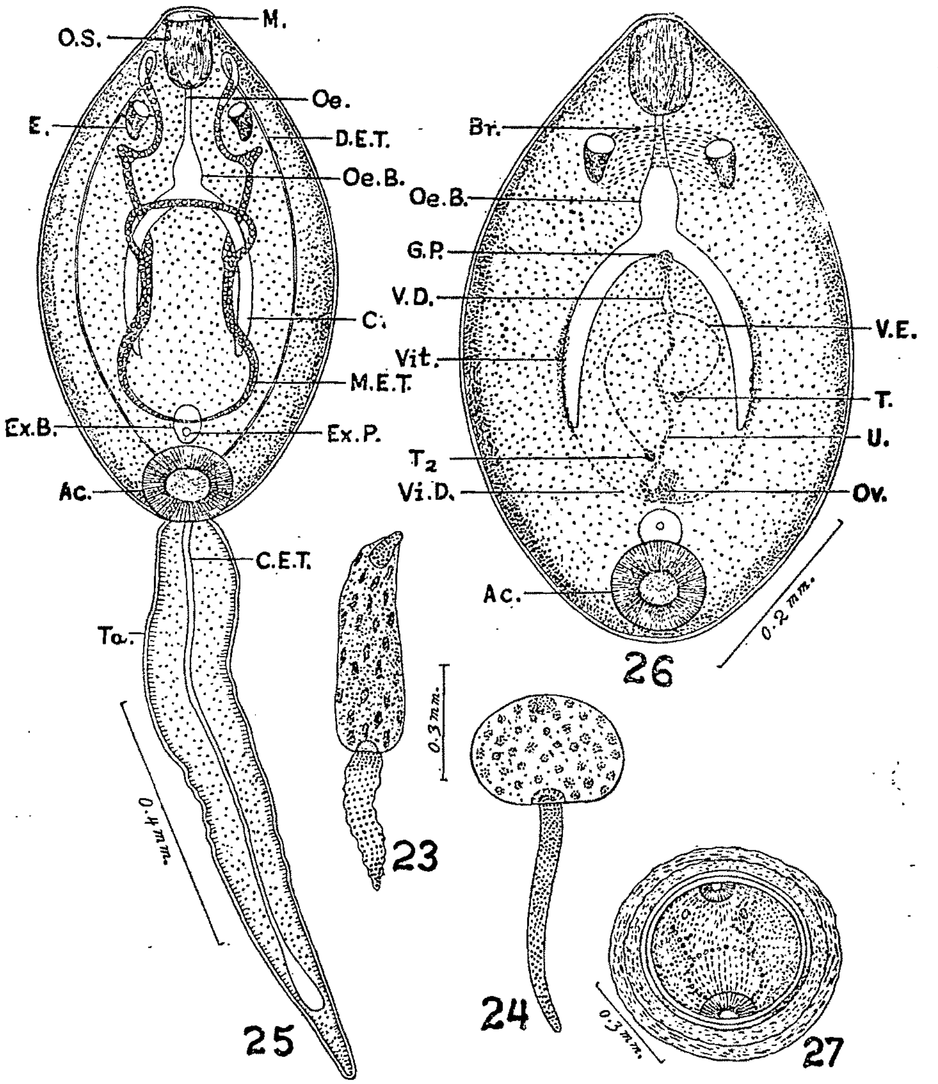
The immature cercaria shows irregular movements. The eyes acquire a heavy pigmentation. They retain their characteristic oval shape for a long time. The pigment begins to spread out from the eyes in lateral, finger-like projections. The colour of the pigment is light black with brownish tinge. The pharynx is differentiated. The rhabdocoel intestine bifurcates, grows laterally and then posteriorly. A group of cells at the posterior end develops into an acetabulum and the tail is demarcated from the body. A caudal excretory tube is still not visible at this stage of development. The main excretory tube and cross-connection are devoid of excretory granules. The main excretory tubes extend upto the region of the eye spots. They originate from the excretory vesicle situated anterior to the acetabulum. As development proceeds further, the cystogenous cells increase in size and completely fill the body. The rudiments of reproductive organs begin to appear.

MORPHOLOGY OF THE MATURE CERCARIA

(Figs. 23-26)

The cercaria of *C. scoliocoelium* belongs to the "Pigmentata" group of Sewell (1922).

It is oval in shape with a long tail at the posterior end. The cuticle is thin and transparent followed by a thin epidermal layer. The cuticular folds are absent. Due to the presence of dark-drown patches of pigments all over the body, the cercaria becomes opaque and dark in colour. The pigments are absent in the area of the oral sucker and the excretory vesicle.



Cercaria and Metacercaria of *Ceylonocotyle scoliocoelium*

Fig. 23 Living cercaria in extended condition.
Fig. 24 Living cercaria in contracted condition.
Fig. 25 Mature living cercaria showing excretory and digestive systems.
Fig. 26 Mature cercaria showing reproductive, digestive and nervous systems (in fixed stained mount).
Fig. 27 Encysted metacercaria.

The cystogenous cells with a number of cystogenous rods appear as a dense mass of small cells distributed unevenly under the cuticle. The cystogenous rods are short and elongated, with smooth corners. The cystogenous cells and rods come out when cuticle is ruptured under the pressure of a coverslip. The cercaria in live-extended, live-contracted, live-flattened and fixed-flattened conditions measure 0·528 mm. × 0·275 mm., 0·279 mm. × 0·347 mm., 0·775 mm. × 0·460 mm., 0·628 mm. × 0·40 mm., respectively. The tail in live-contracted, live-extended, live-flattened and fixed-flattened conditions measure 0·366 mm. × 0·094 mm., 0·677 mm. × 0·071 mm., 0 909 mm × 0·133 mm., 0·782 mm. × 0·120 mm., respectively.

A pair of conical eyes are situated laterally at the level of the posterior end of the oral sucker, with their apex directed posteriorly. The conical portion of the eye with black pigment mass is directed posteriorly and broad clear refractile lens anteriorly. In fixed and flattened specimens, the conical black portion of the eye measures 0·028 – 0·032 mm. in length and the lens measures 0·020 × 0·028 mm. (0·017 – 0·022 mm. × 0·024 – 0·035 mm.).

The acetabulum, situated on the ventral surface at the posterior extremity of the body, is broader than long in living flattened cercaria, but in fixed and flattened specimens it is almost a rounded structure and measures 0·093 mm. (0·088—0·96 mm.) in diameter. The ratio between the diameter of the acetabulum and body length is 1 : 6·8 and between the acetabulum and body breadth is 1 : 4·3. In unflattened and live, contracted cercaria it measures 0·071 mm. (0·066—0·078 mm.) in length and 0·098 mm. (0·094—0·103 mm.) in breadth, but in unflattened and live-extended condition it measures 0·099 mm. (0·091—0·102 mm.) in length and 0·066 mm. (0·060—0·068 mm.) in breadth. In the living flattened condition the ratio between acetabulum and body length is 1 : 6·7 and between the acetabulum and body breadth is 1 : 3·3.

The mouth opens terminally and is surrounded by a well-developed, muscular oral sucker. The mouth opening is without any papillae. In fixed and pressed cercaria, it is an oval shaped structure and measures 0·096 × 0·066 mm. (0·088-0·106 mm. × 0·059-0·073 mm.). The ratio between the length and breadth of oral sucker and those of the acetabulum are 1 : 1 and 1 : 5, respectively. The oral sucker leads into a narrrow tubular oesophagus with a prominent bulbular thickening just before its bifurcation into two intestinal caeca. The bulb measures 0·052 × 0·04 mm. (0·046 mm. – 0·055 × 0·037-0·044 mm.). The oesophagus is 1/5th of the body length and measures 0·133 mm. (0·124-0·14 mm.). The intestinal caeca run parallel to the lateral margins of the cercarial boby and end blindly at the middle of the body length.

The brain mass is situated in between the two eye spots. The nervous system has two ganglia, located just beneath the eyes and connected by a commissure lying dorsal to the oesophagus.

The excretory system in the living cercaria is filled with small refractile excretory granules. Two main excretory tubes originate from the excretory bladder laterally, pass anteriorly upto the sides of the oral sucker where each gives off a small lateral diverticula a little behind the eye. The two main excretory tubes are connected with each other by an arched shaped cross-connection, located just below or at the level of the caecal bifurcation. The cross-connection forms a loop with the main excretory canal of either side through which passes the corresponding caecum. The anterior end of the main excretory tube turns back and the descending excretory tube extends laterally upto the acetabulum. The excretory bladder is situated at the anterior margin of the acetabulum. It is thin-walled and oval to pyriform in shape. It opens on the dorsal surface through a small excretory pore. The caudal excretory tube is devoid of any excretory granules. It originates from the excretory bladder and passes through the middle of the tail. It broadens to form a small bladder at the posterior end of the tail.

The rudiments of two testes, ovary, uterus, vas efferentia, vas deferens and vitelline ducts, vitelline glands and genital pore are represented by masses of cells. The rudiments of these organs can easily be differentiated in stained toto mounts. They are arranged almost in the same manner as in the adult worm.

A large cell mass situated anterior to the excretory bladder represents the ovary and Mehlis' gland and measures 0·028-0·033 mm. in length. Two small groups of cells, diagnol in position and situated in the third quarter of the body, are the rudiments of the testes. They are about 0·058 mm. apart from each other. A group of cells is situated just behind the intestinal bifurcation representing the genital pore. It is located about 2/5ths of the body length from the anterior end. The ovary and genital pore are joined by a slightly wavy cord of cells which represents the uterus and measures about 0·20-0·21 mm. in length. A cord of cells representing vas efferens originates from each testis and runs anteriorly. The two vas efferentia unite a little posterior to the genital pore and form the vas deferens, which runs parallel to the uterus and upto the genital pore. In some specimens, the genital pore slightly overlaps the caecal bifurcation. The vitelline cells are extracaecal and extend upto the level of the junction of two vas efferentia. The rudiments of the two vitelline ducts, extending from the level of caecal termination on either side of the rudimentary mass of ovary and Mehlis' gland, are present.

In all its essential features, the cercaria closely resembles *Cercaria bulimusi* Peter and Srivastava, 1955.

EMERGENCE OF CERCARIA

The cercariae of *C. scoliocoelium* come out of the snail usually in sunlight. The majority of the cercariae emerge usually between 8·00 a.m. to 11·00 a.m, during November and December. The number of cercariae of *C. scoliocoelium* shed by an infected snail is from five to nine per day. When the infected snail is dissected, the fully mature and immature cercariae come out from the snail tissue. The mature cercariae swim sluggishly for a short time and try to encyst.

The free swimming cercaria in water swims vigorously, making continuous lashing movements of its tail. The cercariae swim in small circle for a short time and are then attracted towards the most illuminated part of the container. This activity may continue for from ten minutes to a few hours.

METACERCARIA

(Fig. 27)

Cercariae readily encyst on vegetation. The encysted cercaria is domb-shaped with 0·06 mm. thick cyst wall. The cyst appears as a small spherical body encircled by three concentric rings. The outermost layer is whitish opaque and very thick. The middle layer is brown and refractile. The innermost layer encircles the embryo. In the newly encysted metacercaria, the eye spots, excretory granules, oral sucker and acetabulum can be seen clearly under the microscope. Within 4-5 days the eye-spots become indistinct. The metacercariae on an average measure 0·4 mm. in diameter.

The metacercariae were maintained for more than two months in a petri dish in a thin layer of water at 10°C.

EXPERIMENTAL INFECTION TO THE FINAL HOST

Two clean kids (No. 13 and 17) were maintained in the shed, under conditions precluding possibility of their acquiring any trematode infection during the entire experimental period. They were given tree leaves and clean water. The faeces of the kids were examined daily for two months for the presence of any trematode eggs before giving the infection.

Kid no. 13 was fed a total of 186, 36 to 62 day old; metacercariae on the 5th January, 1966. Kid no. 17 was fed a total of 222 metacercariae on the 21st January, 1966. The metacercariae were 20 to 62 days old. The age of the kids at the time of infection was about two and a half months. From one month after infection, samples of faeces of the kids were examined at intervals of three days. Later on, they were examined for trematode eggs on alternate days for twenty days and thereafter daily.

Kid no. 17 died of pneumonia on the 46th day of infection. On the 11th May, 1956, i.e. 125 days after infection, amphistome eggs were detected for the first time in the faeces of kid no. 13. It showed that the minimum time for parasite to become mature in the kid was 125 days. Durie (1953) reported that *C. streptocoelium* reached maturity in 48 days in sheep and 56 days in cattle. Mukherjee (1962) found that *C. scoliocoelium* reached maturity in 173 days in goat.

The kid was slaughtered on the 10th August, 1966, i.e. 216 days after the infection and 91 days after the appearance of eggs in faeces. The digestive tract, liver and bile ducts were thoroughly examined for amphistomes. A total of 105 adult mature worms (Fig. 28) were recovered from the rumen, which shows that the percentage of development of cercariae in goat was 56·4%. The specimens on detailed examination were found to be referable to *Ceylonocotyle scoliocoelium* (Fischoeder, 1904) Nasmark, 1937.

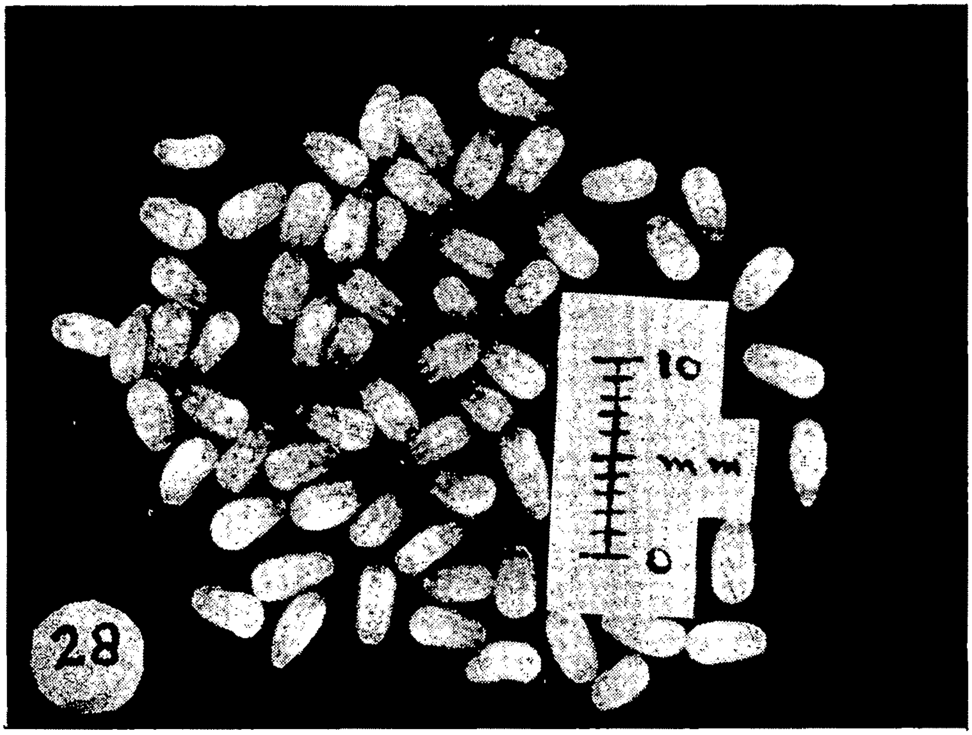


Fig. 28 Adult, mature living worms of *Ceylonocotyle scoliocoelium* recovered from the experimental kid.

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ABBREVIATIONS USED IN THE FIGURES

Ac.	Acetabulum
B.P.	Birth pore
Br.	Brain or nerve mass
C.	Caecum
Cer.	Cercaria
C.E.T.	Caudal excretory tube or trunk.
Ci.	Cilia
D.E.T.	Descending excretory tube.
E.	Eye
Emb.	Embryo
E. S.	Egg shell
Epi. 1	Epithelial cells 1st row
Fpi. 2	,, ,, 2nd row
Epi. 3	,, ,, 3rd row
Epi. 4	,, ,, 4th row
Ex. B.	Excretory bladder or excretory vesicle
Ex. P.	Excretory pore
Ex. V.	Excretory vesicle or excretory bladder
Ex. T.	Excretory tube
F.C.	Flame cell
G.	Gut
G.B.	Germ ball
G.C.	Germ cell
G.P.	Genital pore
M.	Mouth
M.E.T.	Main excretory tube
Mir.	Miracidium
Oe.	Oesophagus
Oe. B.	Oesophageal bulb
Op.	Operculum
Ov.	Ovary
O.S.	Oral sucker
P_1	Apical papillae
P_2	Second row of papillae
P_3	Third row of papillae
P.G.	Penetration gland
P. Gd.	Penetration gland duct.
P.S.T.	Posterior shell thickening
Ph.	Pharynx
R.	Redia
S. P.	Sensory papilla
T_1	Anterior testis
T_2	Posterior testis
Ta.	Tail
Te.	Terebratorium
U.	Uterus
V. C.	Vitelline cell
V. D.	Vas deferens
V. E.	Vas efferens
Vi. D.	Vitelline duct
Vit. M.	Vitelline mass

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STUDIES ON THE DIGESTIVE SYSTEM OF RUMINANTS

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PART I

DEVELOPMENT OF FORE-GUT AND COMPOUND STOMACH IN BUFFALO *Bos bubalis* L.*

The remarkable ability of ruminants in refining course roughages into rich and protective human foods and articles of commerce, which has attracted the attention of great many scientists throughout the world, tempted the authors to investigate Buffalo (*Bos bubalis* L.), because of its commanding position in the realm of dairying in this country. Buffalo not only produces more (about three times that of cow) but also richer milk testing 6 to 9 per cent fat and individuals testing as high as 13% (Kaura 1950) are sometimes reported in Bhadawari breed. As such there is a general consensus of opinion that buffalo is a more economical producer of milk than its counterpart—the cow.

Further, the distinctive and the important role that the ruminants play in the economy of world food production has been attributed to its peculiar digestive system in general and the unique four compartmented stomach in particular. Consequently a large number of scientists all over the world, Sisson and Grossman (1955), Agrawala (1958), Lindhe and Sperber (1959), Paly and Karlin (1959), Davletova (1960), Wardrop and Coombe (1960), Wardrop (1960 and 1961), Brownlee and Elliot (1960), Wing and Ammerman (1960), Quintarelli *et al.* (1960), Phillips *et al.* (1960), Smith (1961), Oyaert and Bouckaert (1961) and Hyden and Sperber (1965), have devoted themselves to the study of the various aspects of ruminant digestion and many of the complicated phenomena have been straightened. But still some of the developmental, structural and functional relationships of the ruminant gut have not been fully unfolded and properly understood.

In the light of the above facts authors got fascinated about the remarkable ability of buffalo to convert poor quality roughages into rich bovine milk and tempted to relate it to the features of their digestive system. Consequently, the investigation "Development and Structure of the Digestive System in Buffalo", was instituted and the information obtained will be reported in several parts. This part deals with the development of fore gut and compound stomach and is planned to know the exact nature of the forestomach compartments and the pattern of their development during pre- and post-natal growth.

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* Part I—Contribution No. A. H. & D. 135/R 84/AS 53.
Part II—Contibution No. A. H. & D. 136/R 85/AS 54.

The practical implication of the developmental studies, therefore, lies in knowing as to what factors affect the development of the digestive system in terms of structure, capacity and function and to what extent their early development, "ahead of schedule", can affect the subsequent feed consumption and utilization. It is quite likely that certain feed additives like volatile fatty acids might prove effective a possibility, that might need exploration.

Lot of work has, however, been done on the prenatal and postnatal development of the digestive system of simple stomached animals including man. But very few workers have attempted to study the digestive system of ruminants, a system which has specialised for the most efficient utilization of roughage and the information on buffalo is altogether wanting. The information collected on the developmental aspect of the digestive system, as envisaged in this part of the study, may throw some light on some of the several unsolved and improperly unfolded mechanisms of the ruminant digestion in general and that of the buffalo in particular. As the term development implies transition from the point of origin to a finite terminus, it is the intention of this part to trace the pattern of development right from the early foetal stage to the adult form.

Because of the nonglandular mucous membrane and the stratified squamous epithelium, rumen, reticulum and omasum are sometimes regarded as oesophageal dilations. However, the embryological studies of Lewis (1915) have shown that such a view is erroneous and these compartments develop from embryonic stomach and not from oesophagus. These compartments may represent regions that have lost their gastric glands while undergoing extensive phylogenetic modifications in size and form caused by the coarse and bulky nature of the food which they have become used to.

Bensley (1902) was, probably, the first to make the statement that the complex stomach of ruminant is developed from the simple stomach because of the continuous specific needs for such development and the oesophagus does not take any part in its development. Pernkopf (1931) also holds the same view and is of the opinion that the lining of the forestomach compartments is not a very specific criterion and is in no way associated with its origin whatsoever. In support of his contention he cites monotemes (Platypus and Echidna), which have simple stomachs lined with Keratinised and stratified squamous epithelium entirely different from the usual lining of the mucigenous columnar type of simple stomach in other mammals.

According to Lambert (1948) first sign of compound stomach in cattle sets in at about the 7 mm. embryo stage as an oval diverticulum connected with the oesophagus which is later on transformed into a typical ruminant stomach as a result of the progressive development. Almost similar situation has been reported in case of buffalo from these laboratories earlier (Lodh 1961 and Tomer 1964).

Development of the bovine stomach during foetal life has also been studied by Becker *et al.* (1951) in cattle. According to them, rumen is the largest oı all the four stomach compartments during early foetal life, while at full term the abomasum takes the first place. The development of the reticular honey comb is noted between 72 and 100 day foetal life and the papillae on omasal laminae develop slowly. The empty stomach is about 1·8 per cent of the total foetal weight during early development, which decreases from 6th month onwards to about 1·3 per cent at the full term.

Fokin (1956), has studied the organogenesis of stomach in cattle using 18 embryos of 28 to 60 days. He is of the opinion that the rumen, reticulum and omasum develop simultaneously, while the abomasum develops a little later. He holds that all the four chambers, however, make their appearance by about 34 to 36 days of gestation, and by the end of two months they acquire their definite shape growing and enlarging topographically with the growth of the foetus. Almost similar findings have also been reported by Davletova (1960), on sheep embryos.

Wardrop (1961), on the basis of his extensive study of the histological development of forestomachs during pre- and postnatal life of lamb, has reported that foetal rumens have smooth mucosa which changes to numerous conical papillae at birth to tongue shaped papillae by about the 56th day of postnatal life. The reticular ribs get visible in 100 day foetus which elaborate till birth. The omasum starts developing laminae at about 46 days of foetal life and by about the 70th day it gets considerably elaborated in terms of various order laminae and the growth of papillae with the progress of gestation.

With increasing emphasis to gain knowledge about the ruminant digestion in general and that of the individual stomach compartments in particular, it becomes increasingly important to study the development of this organ in the growing animal as well.

Parrish and Fountaine (1950) drew their attention to chemical and physical characteristics of the gut contents of calves at birth while Kesler *et al.* (1951), on the other hand, studied the tissues and contents of rumen and abomasum of Holstein calves and concluded that the weight of rumen tissues and contents increased slowly but steadily with marked increase between 4 and 6 weeks of age. They found rumen contents with foul odour and long strands of hay in calves below 4 weeks of age, which changed gradually to resemble the conditions of an adult, when these calves attained 6 weeks of age. They have also reported a highly significant correlation between body weight and rumen tissue and body weight and rumen contents. Almost a similar study has also been reported by Lengemann and Allen (1955).

According to Dukes (1955), the relative size of the four compartments in cattle varies with age. In the new born calf the first three compartments are small and develop as the animal grows and changes from milk to grain-roughage diet. In the newborn, rumen and reticulum together are about one-half as large as abomasum. At about 10 to 12 weeks of age these proportions get reversed and the abomasum gets to only about one-half of the rumen and reticulum combined. At four months of age, rumen and reticulum together measure about four times as large as omasum and abomasum together and at about 18 months of age the four compartments attain about the adult sizes i.e., rumen 80 per cent, reticulum 5 per cent, omasum, 7-8 per cent and abomasum 7-8 per cent of the total stomach capacity.

According to Marshall *et al.* (1950) rumen tissue weight, volume and contents exceeded that of abomasum between 7 to 30 days of life. Huffman (1956) observed a gradual decline in blood sugar and increase in volatile fatty acids in week-old calves maintained on good quality roughages, which indicates that the functional activity can set in as early as that. This has further been elucidated by Brownlee (1956), that it is the energy value of feed which is more important than bulk in inducing the functional state of rumen. He is of the opinion that the development of papillated structure is directly dependent on the energy yielding potency of feed components. Almost similar view is held by Smith and Sobrevilla (1959) who are of the opinion that the quality of roughage plays a major role in inducing the functional state of the ruminant stomach. According to them it takes only about 3 weeks if the roughage quality is good and as many as 18 weeks otherwise. On the other hand Wing and Ammerman (1960), working with steers hold that the development of the other stomach compartments is almost independent of the type of feed, and the dietary factors are important in case of rumen alone.

Tamate (1956 and 1957) while working with kids has concluded that reticulum and rumen develop most rapidly after weaning. Forced weaning earlier than 16 days, may result in "Misgrowth" of rumen. Similarly prolonged milk feeding beyond 53 to 72 days may tend to retard its development. Tamate, and co-workers (1959) tried the effect of various substances on anatomical development of rumen in calf and concluded that acidfed calves began ruminating at about 7 days. However, they did not develop a normal rumen for which the addition of hay and grain were essential.

Flatt, Warner and Loosli (1958), have studied the influence of purified materials on the development of ruminant stomach. They introduced various materials like plastic sponges, cellulose sponges and purified solutions of sodium acetate, sodium propionate, sodium butyrate and sodium lactate in the rumen of calves through fistulae and concluded that the end products of rumen fermentation, rather than the coarse nature of feed, are the stimuli for the development of rumen papillae. These workers again (1959), while studying the factors affecting the development of ruminant stomach and evaluating the various criteria used to determine rumen function, concluded that the measurements of the papillary growth and reticulo-rumen volumes are the most sensitive criteria for evaluating the development of ruminant stomach. They have disproved the theory that the physical nature of feed stimulates the development of rumen and support the chemical theory, indicating thereby that the breakdown products of the feed by rumen microbes are the major stimulatory factors, Sander *et al.* (1959) studied the stimulatory effect of sodium butyrate and sodium propionate on the development of ruminal mucosa in calf and have reported that the treatment favoured the development of rumenal papillae and reticular ribs.

Warner (1960), while referring to the factors affecting the development of ruminant stomach is of the opinion that, of the various volatile fatty acids, butyric acid is most rapidly metabolised by the rumen epithelium in vitro and is followed by propionic and acetic respectively, sequence remaining the same in vivo studies also. Test of fatty acids used singly to stimulate papillary growth indicate that butyric was the most effective, followed by propionic, and the acetic being largely inactive. He has, therefore, suggested the probability of the metabolites of these acids passing through ruminal walls and create biochemical stimulus for the growth of absorptive papillae. He further indicates that the papillae once formed are not permanent and may regress if the effect of volatile fatty acids is withdrawn and/or reduced.

Tamate *et al.* (1962a) also studied the effect of various diets on the anatomical development of the forestomach in calf and concluded that the papillary growth in the rumen was stimulated by the administration of volatile fatty acids. Milk, fed in the rumen, also was equally effective in stimulating the papillary growth. Introduction of plastic sponges into the reticulo-rumen promoted an increase in its capacity and muscular development.

Tamate *et al.* (1962b) again on the basis of their studies on the stomach growth in dairy calves have reported that a better development of the forestomachs was demonstrated by its better papillary and mucosal growth and the increase in tissue weight in calves receiving roughage and concentrates than those receiving concentrates alone. Capacity, however, did not show any difference amongst the different dietary groups.

Comline *et al.* (1951), while working on the route of colostral globulin absorption in a new born animal, are of the opinion that its capacity to absorb large amounts of unchanged colostral proteins disappears within 24 to 48 hours of birth. They have also examined the possibility of globulin absorption into lymph and then carried by it to the systemic circulation. They are of the view that the unchanged globulins along with associated antibodies of colostrum do not enter the portal circulation in appreciable amounts but are carried by lymph to the peripheral blood.

This tempted Hill and Hardy (1956) to make histological and histochemical observations on the intestinal cells of lambs absorbing colostrum. According to them the materials from the lumen of the intestine are absorbed in finally divided form and form the globule within the cell that occupies an infra nuclear position.

The surgery has also been actively involved in the developmental study of the digestive system. Kameoka and Morimoto (1959) prepared goats surgically for the collection of ingesta at its entry into the abomasum and studied the extent of digestion in the forestomach compartments i.e. rumen, reticulum and omasum, while Lupien *et al.* (1962) has gone a step further and surgically removed the forestomachs of calves and demonstrated that the decrease in the blood sugar levels that occurs with the passage of time in normal calves, is independent of rumen development, dietary changes, and increased levels of volatile fatty acids in the functional rumen or in the blood.

Sinclair and Kunkel (1959), working on lambs concluded that the development of rumen along with its mucosa and the length of papillae is an individual trait closely related to body weight and partly to the rate of body gain. Width of papillae seemed to be independent of this effect. They further feel that colour of the mucosa depends upon the microbial products formed and indicates the degree of microbial activity.

Harrison *et al.* (1960) devoted to the changes in the tissue and volume of the calf stomachs fed different diets, are of opinion that the high concentrate ration tends to elongate the ruminal papillae and the reversal to milk diet leads to their disappearance and reduction in the tissue weight but no retrogression in the rumen volume and omasal growth. Calves reared on milk alone or milk plus wood shavings develop no papillae, however, the wood shavings promote considerable development of the rumen musculature. Almost similar observations have also been reported by Smith (1961), who has studied the effect of wood shavings on the development and function of the rumen of milk-fed calves.

Wardrop and Combe (1960) have presented a series of papers on the growth of visceral organs in lambs. According to them rumen has the fastest growth and is followed by reticulum, omasum and abomasum. The different compartments of stomach alter very rapidly in their relative size after birth and the adult proportions are reached by about 56 days of age. Wardrop (1960) is also of the opinion that it is the type, rather than the plane of nutrition, which is more important in determining the weights of the stomachs relative to each other and to liveweight. Milk-fed lambs have retarded development of the forestomachs as against the abomasum which is usually abnormally heavy. The retarded rumens and reticulums attain normal proportions very quickly on feeding roughage.

Warner and Flatt (1965) in an article entitled "Anatomical development of the ruminant stomach", have reviewed in detail the various criteria which have been used by different workers from time to time for studying the growth of ruminant stomach and have made valuable suggestions for further work in that direction.

With all this background it becomes tempting to speculate that by understanding the principles of stomach development in ruminants and getting familiar with the factors that affect it, the process can be controlled in such a way as to benefit the producer. Theoretically an increase in capacity should lead to larger feed intakes and an early development of the papillae should improve absorption of the nutrients and may promote growth and production.

The success of high or all roughage system in feeding dairy animals, which has become essential because of the exploding human population, therefore, depends upon the development of both stomach capacity and function. Encouraging early forage consumption leading to earlier rumen growth and function may lead to superior forage appetite and ultimately better production. This might also have the added advantage of saving milk from the calf and diverting the same for human consumption.

With these considerations in mind, the observations on the developmental aspects of the digestive system of buffalo—an important dairy animal, right from the foetal to the adult stage were planned to gather information on the normal developmental and growth pattern of the digestive system in general and that of the stomach compartments in particular.

MATERIALS AND METHODS

The material for the study of this part was obtained from 150 foetuses and 35 calves of varying age groups. While most of the foetuses were collected from the city slaughter house (Fig. 1.1) most of the calves came from the local military dairy farm. A few aborted foetuses and growing calves were also derived from the nearby dairies and the college herd. The foetuses were carefully removed to the laboratory to determine foetal age after the standards already reported earlier from these laboratories, Singh *et al.* (1963). The ages of the calves, on the other hand, were taken from the record or from the owner.

The foetuses brought to the laboratory were opened for the examination of oral cavity, oesophagus, stomach compartments and the segments of intestine along with liver and pancreas. The tongue, liver, and pancreas were removed by cutting them along their attachments and weighed to record their growth in terms of tissue weight at different stages of prenatal growth. The gut as a whole was then carefully removed right from the oral cavity upto the rectal opening at the anus and separated into oesophagus, rumen, reticulum, omasum, abomasum, small intestine, caecum, colon and rectum using appropriate land marks. These were mechanically cleaned of their contents and mesenteric attachments and measured for length, tissue weight and capacity using metric system. The intestines of early foetuses which could not be successfully uncoiled because of their delicate nature and straugulations with liver, were measured in pieces using magnifying lenses and sterioscopic binoculars (Fig 2.1).

The calves under reference received their full quota of colostrum and the usual quantities of milk directly from their dams until their weaning or slaughter whichever was earlier. After weaning they were fed whole milk and/or separated milk (10% of their body weight) twice a day and were offered calf gruel and/or calf starter mixtures as they grew in age. From about the 15th to 20th day of their birth they were also offered greens and hay adlibitum. The milk was completely withdrawn at the age between 2 to 2·5 months and so also the gruel by about 4 months of age. Then onwards they received reasonably good quality roughages having enough greens and concentrate mixture till the time of their sacrifice.

The calves were operated under deep chloroform anaesthesia about 2 to 6 hours after the ingestion of their normal meals on the operation table with mask on so that it may not recover from anaesthesis during the course of operation (Fig. 1.2). They were opened for the examination of the oral cavity, oesophagus, stomach and the intestines which were carefully examined in situ (Fig. 2.9) and then measured separately.

Material for the histological preparations was taken from the different organs of foetuses and calves at different stages of growth and treated for the histological preparations using standard methods (Lee 1950). The observations made on different organs at different stages of pre- and postnatal growth have been summarised in appropriate tables and wherever possible diagrams have also been used in support of the text.

FINDINGS AND DISCUSSION

The digestive system amongst higher animals is a long winding tube, and is several times longer than the body. It begins with the mouth and ends at the anus. Traditionally it is divisible into three regional divisions, viz., the fore-gut, the mid-gut and the hind-gut (Patten, 1952). The fore-gut which develops from the stomodeal depression (ectodermal in origin) cranially in the embryo, gives rise to mouth, pharynx and oesophagus. The mid-gut (endodermal in origin), is lined by the columnar epithelial cells, and gives rise to the stomach, small intestine and large intestine. The hind-gut on the other hand, develops from the proctodeal invagination (Ectodermal in origin), of the embryo caudally and gives rise to rectum. The accessory digestive glands like salivary, liver, and pancreas develop as the outpocketings of the primitive gut.

The early development of the primitive gut formation and the details of the buccal cavity, pharynx and oesophagus along with their associated structures have not been considered in detail. The earliest specimen, which could be successfully dissected for the study of the digestive system, aged about 40 days. This had primitive gut fully laid down from the mouth to the anus but the different segments were not clearly demarcated. However, a gross differentiation of stomach and intestine in general was possible.

The Buccal Cavity

The floor of the buccal cavity is provided by the mandibular arch (first pair of visceral arch of the embryo). Other associated structures of the oral cavity e.g., tongue, salivary glands etc. develop as evaginations of the oral lining. The gums which are laid down quite early during development remain as soft structures in the beginning and develop ossified core and grow teeth buds only by about the full term. The cheeks also develop their papillae during the later half of the foetal life.

The roof of the oral cavity, on the other hand, is derived from the developing cranium and the secondary palate. The latter is formed as a result of the preaxial growth from the maxillary bones called the trans-palatine processes of the maxilla and ultimately provide the bony base to the hard palate of the adult animals.

The tongue makes its appearance with comparatively thinner margins during the 2nd month of foetal life. It is found broadly and firmly attached to the floor of the oral cavity with a relatively small free portion (Fig. 2.2 and 2.3). With the progress of time the free portion of the tongue, which is bluntly pointed anteriorly, grows relatively faster and keeps pace with the elongating snout of the growing foetus (Fig. 2.4 and 2.5). The measurements of the developing tongue have been summarised in table 1 and graphically represented in figure 3.

TABLE 1

Showing the tongue measurements of different stages of pre- and postnatal growth in buffalo.

Stage of development	Tissue weight measurements		% of empty body weight
	Average (gm.)	% of total digestive (tract)	
	Prenatal Stages		
3rd month	0·06	4·26	0·32
4th month	0·66	10·71	0·74
5th month	2·92	12·07	1·07
6th month	9·37	15·80	0·80
7th month	17·81	15·70	0·77
8th month	24·42	13·69	0·51
9th month	35·44	11·39	0·44
10th month	72·87	13·83	0·47
	Postnatal Stages		
Birth to 5 days	117·75	11·95	0·43
6 to 15 days	131·20	11·65	0·45
16 to 30 days	146·80	9·52	0·44
31 to 60 days	172·60	7·62	0·42
61 to 120 days	218·40	6·38	0·41
121 to 515 days	444·20	6·68	0·42
Adult	1485·48	6·12	0·37

From table 1, it is seen that the tongue has an increased growth in proportion to body upto the 5th month of foetal life (in accordance with head growth) and then declines to the full term, through calf stage down to the adult when it accounts for 0·37 per cent of body weight only. It was noted that the different kinds of tongue papillae, reported in case of adult, do not develop until about the middle of foetal life. These, however, gain their form by the end of full foetal term.

The Oesophagus

The oesophagus (Fig. 4) has its origin as a delicate membranous tube connecting the oral cavity with the primitive stomach. It is a short tube with thin walls (Fig. 4·1) to start with, which grows in length and develops both muscularis and mucosae with age of the foetus (Fig. 4·5). The detailed observations made on the measurements of the developing oesophagus during pre- and postnatal growth are summarised in table 2 and graphically represented in figure 3.

TABLE 2

Showing the oesophageal measurements at different stages of pre- and postnatal growth in buffalo.

Stage of development	Linear measurements			Tissue weight measurements		
	Average (gm)	% of total gut length	% of body length	Average	% of total gut	% of empty body weight
			Prenatal Stages			
2nd month	0·91	18·42	65·00	...	...	...
3rd month	2·72	8·12	71·58	0·05	3·55	0·27
4th month	4·55	4·87	65·66	0·15	2·44	0·17
5th month	7·34	3·92	59·15	0·83	3·44	0·30
6th month	13·84	3·53	76·63	3·03	5·11	0·26
7th month	17·89	3·42	79·51	5·88	5·19	0·25
8th month	23·42	3·64	76·11	8·15	4·57	0·17
9th month	33·05	3·85	81·81	11·46	3·63	0·14
10th month	37·45	3·84	72·79	18·90	3·59	0·12
			Postnatal Stages			
Birth—5 days	45·75	4·06	79·57	36·00	3·66	0·13
6—15 days	51·50	3·16	86·19	42·80	3·80	0·15
16—30 days	53·50	2·72	86·07	45·20	2·93	0·13
31—60 days	59·17	2·46	92·38	57·60	2·54	0·14
61—120 days	62·20	2·44	90·41	75·40	2·21	0·14
121—515 days	73·20	2·42	87·88	202·00	3·04	0·19
Adult	98·72	2·45	67·99	676·64	2·79	0·17

It is seen from table 2 that oesophagus remains an insignificant organ upto the 2nd month of intra-uterine life. With the straightening of the foetal posture at about the middle of the 2nd month, it gains in length and assumes a well defined form with the elongation of the neck by about the end of 3rd month of foetal life.

It is further seen that while its absolute length increases in almost geometrical progression during the first half of the intra-uterine life, its proportion to the total gut length shows a declining trend in the beginning and then gets almost constant to account for about 4 per cent of the total gut length. After birth it declines further to about 2·5 per cent which means an alometric growth of other parts in relation to it and this is maintained through postnatal growth upto the adulthood. As far as the tissue weights are concerned it makes about 3 to 3·5 per cent of the total gut tissue by weight. This, however, does not apply during 6th, 7th and 8th months of foetal growth when the oesophageal tissues have an allometric growth trend.

After birth the oesophageal tissues, account for about 2·5 to 3·5 per cent of the total empty digestive tract by weight. Both length and tissue weight of the oesophagus have also been represented as part per hundred of pin-shoulder length and empty body weight respectively in table 2, which, however, does not make any definite trend.

Histologically, the growing oesophagus shows interesting changes both in its musculature and mucosa which can be seen from figures 4.1 to 4.5 in sequence. These figures indicate that during early foetal stages (50 days), the oesophageal walls have well defined muscularis and mucosa. The mucosa, which is almost smooth and without folds, has a well defined epithelium resting on a basement membrane and is covered with a single layer of squamous cells (Fig. 2.1). There exists no distinction between the lamina propria and the submucosa as the muscularis-mucosae is not developed at this stage. Both propria and submucosa largely have a cellular nature with well defined nuclei, the connective tissue fibres having not yet developed.

The basal cells of the mucosal epithelium have a cuboidal shape and keep apposed with each other along their long axis. Their oval nuclei are centrally located and fill most of their space (Fig. 4.2). The nuclei of the squamous cells, on the other hand, are located in the apical halves of the cells (Fig. 4.2).

With the progress of time, both, muscle and the mucosae elaborate. More squamous cell layers are added (Fig. 4.3) to the mucosal lining and the muscle layers also grow in thickness (Fig. 4.4), so much so that by about the middle of gestation, the foetal oesophagus develops almost all those features true of an adult, except that the squamous cells do not get keratinised. The blending propria and the submucosa get differentiated with the development of muscularis mucosae and the two start changing their cellular nature to that of the fibrous type (Fig. 4.4).

By about full term the keratinization sets in the top squamous cells of the epithelium. At birth it gets fully cornified to resemble that of adult in almost all respects (Fig. 4.5). The epithelium of mucosa gets deeply indented by the papillae of the subjacent lamina propria, which, however, do not make any prominence on its free surface.

The oesophageal groove along with its muscular lips starts developing by about the beginning of 3rd month of gestation (Fig. 4.6). It appears that the two lips of the groove do not develop simultaneously and do not have the same magnitude of growth. The one which is towards the rumen develops a little more elaborately than the other. It consists of a thick core of the longitudinal muscle fibres, which remain continuous with the oblique ones of both rumen and reticulum, and are sandwiched in between the layers of submucosa and mucosa which is disposed on their three sides.

The lips develop and elaborate with the passage of time and by about the mid term of intra-uterine life the complete groove in its miniature form is laid down (Fig. 4.7) and the layers of squamous cells over the pillars decrease in number. The oblique muscle fibres which are abundantly distributed in the wall of rumen and reticulum and form bulk of the lips, however, are missing from the wall forming floor of the groove which contains the circular set of bundles only.

By about full term, the groove and the lips elaborate further (Fig. 4.8) and acquire the characteristic ruminal pattern of mucosa in the upper, and the reticular one in the lower part. After birth it grows in accordance with the reticulum upto the adult stage.

The working pattern of the oesophageal groove has been studied by Hegland *et al.* (1953 and 1957). Through carefully planned experiments they could establish that all kinds of liquids are able to cause the reflex closure of oesophageal groove upto the 8 weeks of age irrespective of the method of feeding i.e., nipple or pail. After 8 weeks of age the efficiency of this reflex closure diminishes and about 25 per cent or more fluids manage to pass into the rumino-reticulum. It, therefore, appears that the efficiency of the reflex closure of the oesophageal groove is in some way related to the absolute milk feeding regime of the calf.

The Stomach

The stomach in an early embryo is represented by a simple dialation, just posterior to the stomodeal portion. It is from this simple dilation that the various compartments, viz., rumen, reticulum, omasum and abomasum get differentiated with the growth of the foetus (Fig. 5).

The Rumen

The rumen is the first compartment that gets differenciated from the primitive stomach. Even in a 40 day foetus it can be conceived as a small sacculation oriented dorso-anteriorly to the reticular portion of oesophageal attachment (Fig. 5.1), while the other two compartments still remain as almost a single enlargement. It gets further differenciated and elaborated with the passage of time and by about the end of 2nd month of foetal growth all the four compartments get fully established and all of them lie in a cranio-caudal straight line (Fig. 5.5). It is only with the beginning of 3rd month that because of the differential growth different compartments start reorienting themselves with regard to their relative positions. As a result of this the apparent straight line cranio-caudal continuity of the various compartments is lost and the rumen starts occupying the ventro lateral position. A small notched depression sets in at the blind end of this sac (Fig. 5.7) and marks the beginning of the ruminal grooves and ultimately makes the posterior transverse groove dividing the organ into two lateral sacs (Fig. 5.8). The other grooves, described for adult, follow and develop almost simultaneously and get elaborated with age.

It finally turns clockwise through about 90° on its longitudinal axis and then rotates on its transverse axis at the point of oesophageal attachment to 180° such that its transverse axis, which was almost horizontal to start with, gets vertically directed and the original longitudinal axis is completely reversed. As a result of this the anterior right sac of the rumen becomes the posterior dorsal, while the anterior left becomes the posterior ventral. By the beginning of 4th month, therefore, the rumen gets well elaborated and topographically reoriented (Fig. 5.12). Its different grooves and the corresponding pillars develop with the passage of time (Fig. 5). It is only at about the 8th month of foetal life that rumen papillae are seen developing as conical structures, which grow progressively both in size and number and get quite numerous by the full foetal term. After birth the papillae continue to grow in size, elaborate in form (Fig. 6.3-6.9) and develop papillary bodies as the calf takes to roughage diet and becomes adult (Fig. 6.10 and 6.11). The detailed measurements made on the developing rumen both during prenatal and postnatal growth are summarised in table 3.

From table 3, it can be seen that rumen is the largest stomach compartment even during the early foetal life. At about 2·5 month's of foetal age it makes 72 per cent of the total stomach and about 1 per cent of the body of tissue weight. It then grows allometrically upto the 5th month of intra-uterine life by when its tissue weight accounts for about 2 per cent of the body. Then onwards its rate of growth has a declining trend upto full term. As per cent of the total stomach it indicates a gradual decline althrough during the prenatal life. The tissue weight averages obtained for the foetal rumens in this investigation compare fairly well with those of Becker *et al.* (1951) reported for cattle of nearly identical stages of foetal growth.

The declining trend in the rumen tissue weight, both as per cent of total stomach and of body, continues till the calf is born. It is only after about a week or so that it starts gaining back gradually. This increase in rumen tissue is slow during the early milk feeding regime and gets significantly marked after the calf has taken to roughage eating at about 4 weeks of age. It then grows rapidly and assumes almost normal proportion of adult at the age of about one year when it accounts for 55·31 per cent of the total stomach and 2·16 per cent of the empty body by weight as against 58·42 per cent and 2·48 per cent that of the adult respectively. The rumen tissue as per cent of the total digestive tract tissue, however, does not make any definite trend during foetal growth but during the postnatal life it has an increasing trend changing from about 11 per cent at birth to about 41 per cent of the adult.

The relative capacity of rumen (as per cent of total stomach capacity) gradually increases upto the 6th month of foetal life, when it accounts for about

75 per cent of the total stomach capacity, and then gradually declines to full term of intra-uterine life. It starts gaining back again after the calf is born and reaches to about 80 per cent of the total stomach capacity at the age of about 400 days, as against 88·13 per cent of the adult. During the postnatal growth rumen extends backwards, dorso-ventrally and to the left with the growth of the calf and its change from milk to roughage diet (Fig. 6.1 and 6.2).

TABLE 3

Showing the ruminal measurements at different stages of pre- and postnatal growth in buffalo.

Stage of development	Tissue weight measurements				Capaciy measurements	
	Average (gm)	% of total stomach	% of total digestive tract	% of body weight	Average (cc)	% of total stomach
			Prenatal Stages			
3rd month	0·18	72·00	12·77	0·98	...	...
4th month	0·96	48·48	15·58	1·08	3·67	46·22
5th month	5·25	43·82	21·70	1·92	17·33	68·88
6th month	13·58	44·23	22·90	1·15	38·00	74·74
7th month	24·21	40·82	21·35	1·04	54·83	72·35
8th month	31·12	35·11	17·45	0·64	87·33	70·43
9th month	40·44	35·37	12·80	0·50	165·00	60·59
10th month	85·87	40·92	16·30	0·54	308·33	48·34
			Postnatal Stages			
Birth to 5 days	108·75	28·66	11·05	0·39	653·33	32·18
6 to 15 days	141·00	29·92	12·52	0·49	1780·00	43·66
16 to 30 days	235·00	38·93	15·23	0·70	2996·66	50·95
31 to 60 days	421·60	43·24	18·61	1·03	8200·00	61·63
61 to 120 days	834·00	49·85	24·40	1·57	23333·33	71·99
121 to 515 days	2305·00	55·31	34·66	2·16	58766·66	79·98
Adult	9906·92	58·42	40·84	2·48	168400·40	88·13

It may, therefore, be interpreted to mean that the growth of rumen tissue and capacity during postnatal life have something to do with the roughage consumption. This coroborates the findings of Flatt *et al.* (1958), Tamate *et al.* (1959 and 1962), Harisson *et al.* (1960), Wardrop (1960) and Smith (1961) who have, through carefully planned experiments, clearly established that the ingestion of roughage and the end products of crude fibre digestion are primarily responsible for the growth and elaboration of this organ.

Histologically, the rumen makes a humble beginning. Irrespective of its dilated gross appearance at about the 50th day of foetal life, it has thin walls which have the blue prints of all the layers described for an adult. The outermost serosal lining is extremely thin with narrow band of areolar tissue margined by the flattened cells of the visceral peritoneum (Fig. 7.1).

The underlying muscularis consists of individual fusiform muscle cells with marked elliptical nuclei which have not organised into definite muscle fibres and bundles (Fig. 7.1). However, the pattern of their disposition indicates that they are in the process of arranging themselves into definite layers described for an adult. The beginning of the formation of ruminal pillars and the corresponding grooves also sets in quite early during development. At about the beginning of third month of intra-uterine life they start developing as invagination of the wall and the concentration of muscularis into these invaginations (Fig. 7.2). These spots then elaborate with the growth of the organ to attain the final form.

The next submucosal layer which has a marked fibrous appearance in adult, is distinctly cellular at about 50 day foetal stage and the cells with prominant nuclei are irregularly distributed. Because of the absence of muscularis mucosae it blends with the lamina propria of the mucosa and the two are hard to be distinguished from each other (Fig. 7.1).

The mucosal epithelium is also much simpler than that of the adult. Its basal layer consists of cuboidal cells with a distinct basement membrane. They are disposed in a single layer with their long axis almost perpendicular to the mucosal surface and have an uneven top line because of their active proliferation. Their nuclei are usually oval in shape and almost centrally located to occupy most space of the cell.

The basal layer of mucosal epithelium is covered with a layer of squamous cells (4 to 6 cell layer thick) with almost rounded nuclei located at the lumen-end half of the cells. Almost all the cells of squamous layer maintain their long axis vertical to the mucosal surface and there are no symptoms of keratinization whatsoever.

With progress in gestation the foetal rumen elaborates both its muscularis and mucosa and the submucosal layer comparatively decreases in prominence. By about the middle of gestation the muscle layers grow quite prominent and the submucous layer changes to fibrous nature due to the development of collogen fibres with relatively fewer nuclei (Fig. 7.3).

The lamina propria of mucosa which was indistinctly separated from the underlying submucosa in the beginning gets distinctly marked off as a separate layer consisting of free cells with prominent nuclei. During the second half of foetal life it starts entering into the core of conical papillae that develop from the basal cell layer of the mucosal epithelium evaginating into the squamous layer of the same, which grows considerably thick and attains a few dozen cell layers (Fig. 7.3). The basal cells still rest on a well defined basement membrane that separates them from the subjacent lamina propria. The squamous cells on the other hand have a fusiform shape towards the basal layer and are vertically arranged as against the flattening out ones towards the lumen which acquire a tangential disposition and line the lumen smoothly.

At the close of the gestation period the rumen wall of foetus gets further elaborated in its muscularis and mucosae. The submucosal tissue, on the other hand, is reduced to a bare minimum as most of it runs into the core of fast growing ruminal papillae. These grow numerously from the basal layer of the mucosal epithelium into the squamous layer which gets reduced in the number of cell layers by this time. The inner most lining of the squamous cells which was smooth so far starts developing domes and depressions over and in between the developing papillae, such that each papillae is surrounded by a layer of squamous cells (4 to 6 layer thick) on all sides and top (Fig. 7.5). Identification of the typical five layers, described in case of adult, are not quite marked during the prenatal stages.

The lamina propria is lost from the general wall and runs almost completely into the core of the papillae along with some of the subjacent submucosa and vessels.

The layers of squamous epithelium towards the lumen get further flattened and the innermost layer lining the lumen starts getting parakeratotic and changes to the keratinized one in newly born calf (Fig. 7.6). At birth a good portion of papillary length is found burried in the squamous cells that form a continuous layer at their bases. At this stage the papillae are so densely populated that there is hardly any interpapillary space to be located. As the interpapillary spaces increase with age, their density per unit area decreases. In some cases it was possible to see some of the large papillae splitting up into two or even three smaller ones (Fig. 7.7).

During the milk feeding regime of calf, however, there is not much change except that the papillae develop papillary bodies with inpushings of the lamina propria and the keratinized and parakeratotic cell layers get 3 to 4 in number (Fig. 7.8). It is also observed that as a rule the mucosal thickness of the dorsal chamber is more than that of the ventral. Again the mucosal thickness is more in between the papillae than on the papillae. With the ingestion of roughage by the calf the keratinized layers probably get denudated and slaughed off so much so that the adult has only, about one layer, which, too, may be missing in some portions. The underlying cell layers which remain simple during the milk feeding regime (Fig. 7.6) reveal swollen appearance in case of adult.

The detailed measurements made on the papillary growth and their changing pattern during the postnatal life in this class of animal are contained in table 4.

TABLE 4

Showing the observations on the ruminal papillae in 1 cm. discs (0·7857 sq. cm.) of rumen wall taken from the anterior dorsal sac at different stages of postnatal growth in buffalo.

Stages	Age in days	No. of papillae	Average length of papillae (mm)	Average width of papillae (mm)	Gross shape of papillae	Colour of mucosa
Birth to 5 days	2·50	270·50	0·67	0·34	Conical	Pale white
6 to 15 days	12·00	169·00	1·07	0·56	Conical to finger like	Pale white to pale
16 to 30 days	23·00	134·33	1·25	0·65	Conical to finger like	Pale white to pale yellow
31 to 60 days	47·00	98·88	2·29	0·83	Finger like to foliate	Pale yellow to light brown
61 to 120 days	91·20	79·60	3·52	1·05	Foliate	Brown
121 to 515 days	346·40	57·60	4·26	1·41	Foliate	Brown to dark brown
Adult	Over 5 years	21·11	10·45	2·43	Foliate	Dark brown

From table 4, it is seen that in newly born calf the papillae are numerous with pointed tips and so closely packed that there is no interpapillary space (Fig. 6.3 and 6.4). With the passage of time they grow in size and elaborate in shape. During milk feeding regime, however, they do not make much progress. They start attaining their characteristic features from the time calf starts eating solid food. The papillae change from conical (Fig. 6.3) through finger shaped (Fig. 6.5) to foliate (Fig. 6.7) in shape and elaborate both in length and width with the growth of the calf and by about the 3rd month of age they assume adult form and disposition which is characterized by the development of papillary bodies and fissures and furrows on them (Fig. 6.10 and 6.11).

The colour of the papillary and interpapillary mucosa, which is almost white at birth, changes to pale white and yellowish during the milk feeding regime. With the ingestion of roughage and concentrate it starts developing a darker colour and changes from light brown through brown to dark brown depending probably upon the intensity of fermentation in the rumen. By this time the wall which essentially has two layers of muscle bundles, the outer longitudinal and the inner circular, develops a third layer of oblique bundles also which may be treated to have arisen from the circular muscle bundles with which they remain almost continuous.

The Reticulum

The reticulum is the second compartment of ruminant stomach. It is the first to get differenciated from the common reticulo-rumen at about the 40th day of the foetal life (Fig. 5.1). At this stage it looks larger than even rumen, but is taken over by the latter soon at about the 60th day of foetal life (Fig. 5.5). Its relative position lies posterior to the rumen as a small rounded pouch and gets changed to the anterior with the rotation of different stomach compartments, described earlier. The oesophagus which is attached to it also gets twisted and it appears quite likely that the spiral disposition of the oesophageal groove is because of this twist.

Internally the reticular mucosa remains almost smooth upto the 7th month of foetal life and it is only during the 8th month that it starts developing the reticulated reticular ribs. Although some impression of these ribs could be had even earlier than this but the definite development of ribs did not take place until about 8th month of prenatal life.

Detailed measurements on the reticular development both during pre- and postnatal growth are summarised in table 5.

TABLE 5

Showing the reticular measurements at different stages of pre- and postnatal growth in buffalo.

Stage of development	Tissue weight measurements				Capacity measurements	
	Average (gm)	% of total stomach	% of total digestive tract	% of body weight	Average (cc)	% of total stomach
			Prenatal Stages			
3rd month	0·01	4·00	0·71	0·05	...	...
4th month	0·20	10·10	3·25	0·22	1·50	18·89
5th month	2·00	16·69	8·26	0·73	2·43	9·66
6th month	4·12	13·42	6·95	0·35	4·17	8·20
7th month	8·78	14·80	7·74	0·38	5·67	7·35
8th month	13·10	14·78	7·34	0·27	8·83	7·12
9th month	16·60	14·52	5·25	0·20	21·33	7·83
10th month	19·46	9·27	3·69	0·12	48·33	7·58
			Postnatal Stages			
Birth to 5 days	24·25	6·39	2·46	0·09	126·66	6·24
6 to 15 days	30·40	6·45	2·70	0·10	184·33	4·52
16 to 30 days	42·40	7·03	2·75	0·12	323·33	5·50
31 to 60 days	63·40	6·50	2·80	0·16	516·66	3·88
61 to 120 days	142·80	8·54	4·18	0·27	610·00	1·89
121 to 515 days	380·80	9·14	5·73	0·36	846·66	1·15
Adult	1779·64	10·49	7·34	0·44	1786·00	0·93

From table 5, it is seen that the reticulum both as per cent of stomach and per cent of body has an allometric trend similar to rumen during the first half of foetal life and makes 16·69 per cent and 0·73 per cent of the total stomach and body by weight at about 130 days of intra-uterine life respectively. It then declines to get fairly constant in the second half of the foetal growth and drops down still further to account for only 9·27 per cent and 0·12 per cent of the total stomach and empty body respectively at about the end of the foetal life.

At birth these proportions were found to be 6·39 per cent and 0·09 per cent of the total stomach tissue and empty body weight respectively. It then grows slowly but steadily upto one year's of age to account for 9·14 and 0·36 per cent of the total stomach and empty body by weight, as against 10·49 and 0·44 per cent of the adult respectively. The reticular capacity as per cent of the total stomach capacity, on the other hand, shows a declining trend althrough.

Histologically, the reticular walls resemble those of rumen at about the 50th day of foetal stage in the disposition of various tissue strata (Fig. 7.9). The total thickness of the wall, however, was more in case of reticulum than rumen of the same age (Fig. 7.1 and 7.9). Of the individual layers the muscularis of reticulum is more elaborately developed than that of rumen and disposed in two sets of distinct bundles—the outer longitudinal and the inner circular. The submucosa is almost similar to that of rumen and is likewise indistinctly separated from the lamina propria of the mucosa with which it blends and like that of rumen no muscularis mucosae is present in this organ also.

The basal layer of the mucosal epithelium is also almost similar to that of rumen of the identical age but its covering with squamous cells is considerably thicker than that of rumen (Fig. 7.9). Of these more than 50 per cent towards the basal layer have long axis of their cells disposed perpendicular to the mucosal surface and the remaining towards the lumen have an increasing tendency of flattening out at the approach of lumen. Their nuclear and other details, however, remain similar to those of rumen described earlier.

By about the middle of gestation the basal layer of the mucosal epithelium starts folding to mark the beginning of reticular ribs and assume the characteristic wavy disposition (Fig. 7.10). As these folds grow and project into the squamous layer, portions of lamina propria and submucosa enter into them. By about the 8th month of intra-uterine life; the wavy disposition of the basal layer deepens further and changes to that of cup like in appearance. The double walls of these cup like structures get quite close to each other and burried within the deep layers of the squamous cells covering the epithelium and do not project out into the lumen whatsoever (Fig. 7.11).

At the close of gestation and completion of the full term of the intra-uterine existence, the reticular rib projections grow further and simultaneously the squamous cell layers decrease in number. This makes them project into the lumen as clearly visible ribs along with a covering of squamous cells with innermost 2 to 3 layers getting parakeratotic. Peculiarly enough at about this time the reticular ribs which were conical so far develop swollen upper free portions (Fig. 7.12). These ribs, in addition to lamina propria, submucosal tissue and vessels also develop smooth muscle bundles running along their lengths. This according to Trautmann and Fiebiger (1957) is considered to be continuous with the muscularis mucosae of the oesophagus.

The reticular ribs also develop papillary bodies on all their surfaces and contain the inpushings of proprial and submucosal tissue also, as described in case of rumen, after the calf is born and takes to roughage eating. The muscularis also gets disposed in three distinct layers, the outer longitudinal, the middle circular and the inner oblique, characteristic of an adult and described for rumen earlier. Of these the oblique ones are most highly developed and appear to have arisen from the inner bundles of circular muscles with which they remain continuous.

The Omasum

Omasum, the third compartment of ruminant stomach, which remains indistinctly separated from the abomasum in the beginning (Fig. 5.1), gets distinctly marked from it at about the 50th day of foetal life (Fig. 5.4). At this stage it is located posterior to the rumino-reticular buldge and its relative position also changes with the rotation of the other stomach compartments duing the 3rd month of intra-uterine life and finally it comes to lie on the right side of the rumino-reticular sac by about the 4th month of foetal life (Fig. 5.13).

It was, however, noted that although its apparent demarcation appears after that of rumen and reticulum, it has its internal laminae elaborated quite early during development as they could even be identified at 41 day stage of foetal growth. The detailed observations on the development of omasum both during pre- and postnatal growth are summarised in table 6.

From table 6, it is seen that the omasal tissue has proportionately an increasing trend upto the 8th month of foetal life and then declines afterwards and gets almost constant after birth to the 30th day of postnatal life. It starts gaining back again when the calf takes to roughage feeding from the 2nd month of age and ultimately accounts for 19·48 per cent of the total stomach tissue by weight at one year's age as against 17·74 per cent of the adult.

The capacity measurements, on the other hand, indicate that it remains almost insignificant during the foetal stage and also during the milk feeding regime. It, however, makes considerable gains after the calf starts consuming roughage and takes to rumination.

Histologically, it appears that, of the three forestomach compartments, omasum has the earliest elaboration. Like rumen and reticulum, the omasum also has the usual four layers in its walls including the outermost serosal covering, the next muscular coat, the middle relatively deficient submucosa and the innermost mucosa. Samples taken from the foetuses, running 2nd month of their intra-uterine life indicate that their musculature is comparatively better developed than that of the rumen and reticulum of the same age.

TABLE 6

Showing the omasal measurements at different stages of pre- and postnatal growth in buffalo.

Stage of development	Tissue weight measurements				Capacity measurements	
	Average (gm)	% of total stomach	% of total digestive tract	% of body weight	Average (cc)	% of total stomach
			Prenatal Stages			
3rd month	0·02	8·00	1·42	0·11	...	...
4th month	0·37	18·69	6·01	0·42	0·77	9·70
5th month	2·41	20·12	9·96	0·88	1·23	4·89
6th month	7·58	24·69	12·78	0·64	2·00	3·93
7th month	16·60	27·98	14·64	0·72	3·17	4·10
8th month	24·10	27·19	13·51	0·50	4·33	3·49
9th month	26·42	23·11	8·36	0·33	7·00	2·57
10th month	27·02	12·88	5·13	0·17	12·83	2·01
			Postnatal Stages			
Birth to 5 days	31·50	8·30	3·20	0·11	25·33	1·25
6 to 15 days	37·60	8·02	3·36	0·13	46·00	1·13
16 to 30 days	51·60	8·55	3·35	0·15	105·00	1·79
31 to 60 days	134·00	13·75	5·91	0·33	223·33	1·68
61 to 120 days	279·00	16·68	8·16	0·53	636·66	1·96
121 to 515 days	811·80	19·48	12·21	0·76	1026·66	1·40
Adult	3008·56	17·74	12·40	0·76	3965·60	2·08

The omasal mucosa on the other hand is most elaborately disposed amongst the different compartments of the forestomach. It is thrown into omasal laminae in which atleast two-order laminae can be identified even at 50 day stage (Fig. 8.1). Each lamina has a dome shaped or finger like appearance with swollen free margin. It is formed by the inward folding of the basal cell layer of the mucosal epithelium along with its covering of the squamous cells, which may be about 2 to 3 cell thick. The two layers of the invaginating stratum basale remain quite apart from each other and contain lamina propria and a good portion of the submucosal tissue between them (Fig. 8.1). The cells of the smooth muscle from the muscularis are also seen pushing into the core of the lamina which would be forming the central muscle running along the laminal length. No muscularis mucosae either in the region of the omasal wall or its laminae could be identified at this stage (Fig. 8.1).

With the progress of time the omasal laminae elaborate further and it appears that they do it at the cost of outer layers of the omasal wall which proportionately do not develop. Whole of the propria, a greater portion of submucosa and a good portion of the muscularis enter into the laminae (Fig. 9.2). In addition to the first two order laminae a third order is also seen but their core still remains without an organised central muscle and the muscularis mucosae are yet to develop. The squamous cell layers (2 to 3 cell thick) also do not increase in number, a feature which is unlike that of rumen and reticulum. Of the muscularis the outer longitudinal muscles are least prominent and the circular ones also appear to have proportionately dwindled down.

By about the last quarter of the foetal term (Fig. 8.3) the core of the lamina decreases in which, their central muscle fibres start getting prominent and the fibres of the muscularis mucosae on either side of the central muscle in the laminae get evident. Simultaneously the squamous cell layers increase (6 to 8 cell layers) in number and the basal cell layer of the mucosa starts evaginating into the squamous layers to form the so called papillary bodies (Fig. 8.4). A good number of vessels are also seen in the core of the laminae by about the full foetal term.

The changes in the squamous cell layers are almost similar to those of rumen and reticulum and as in their cases, the various zones, characteristic of the adult, are not yet marked out. However, the outer few layers start flattening out but there is no keratinization whatsoever. The papillary bodies consisting primarily of lamina propria, go on increasing in number and by about delivery time their outermost squamous layer starts getting parakeratotic and the total depth of the squamous cells increases.

After the delivery of calf, the parakeratotic nature of the squamous cells, covering the laminae changes to the keratinised one and the papillary bodies elaborate both in size and number (Fig. 8.6 and 8.7) as the calf takes to roughage eating. The thickness of the squamous cell layers, covering the laminae, also reduces and is left only to 3 or 4 in the adult.

The Abomasum

Abomasum, the last compartment of ruminant stomach, also called true stomach, is comparable to the stomach of non-ruminants in the sense that it is glandular in nature and secretes juice containing digestive enzymes. It is not only last in sequence of arrangement but is also last to be differentiated from the common omaso-abomasal mass at about the 50th day of foetal growth (Fig. 5.4). To start with, it is coma shaped and lies closely adapted on to the three sides of the indistinctly separated omasum. Its two regions, viz., the fundus and the pylorus, however, are still not clearly marked out but some indication of the two can be had even at this stage.

With the progress of time the fundus elaborates as a wide, thin walled sac as against the pylorus which has a comparatively narrower diameter and elongated shape with comparatively thicker walls. By about middle of the 3rd month of foetal life it comes to account for about 16 per cent of the total stomach by tissue weight (Fig. 5.8). Detailed measurements recorded on the growth of abomasum during the course of this investigation are summarised in table 7.

TABLE 7

Showing the abomasal measurements at different stages of pre- and postnatal growth in buffalo.

Stage of development	Tissue weight measurements				Capacity measurements	
	Average (gm)	% of total stomach	% of total digestive tract	% of body weight	Average (cc)	% of total stomach
			Prenatal Stages.			
3rd month	0·04	16·00	2·84	0·21	...	...
4th month	0·45	22·73	7·31	0·51	2·00	25·19
5th month	2·32	19·37	9·59	0·85	4·17	16·57
6th month	5·42	17·65	9·14	0·46	6·67	13·12
7th month	9·73	16·40	8·58	0·41	12·50	16·20
8th month	20·31	22·92	11·39	0·42	23·50	18·96
9th month	30·86	27·00	9·77	0·38	79·00	29·01
10th month	77·50	36·93	14·71	0·49	268·33	42·07
			Postnatal Stages			
Birth to 5 days	215·00	56·65	21·83	0·78	1225·00	60·33
6 to 15 days	262·00	55·61	23·27	0·90	2066·66	50·69
16 to 30 days	274·60	45·49	17·80	0·82	2456·66	41·76
31 to 60 days	356·00	36·51	15·71	0·87	4366·66	32·81
61 to 120 days	417·00	24·93	12·20	0·79	7833·33	24·16
121 to 515 days	670·00	16·07	10·07	0·63	12833·33	17·47
Adult	2262·88	13·35	9·33	0·57	16922·40	8·86

From table 7 and Fig. 5, it is seen that abomasum accounts for about 23 per cent of the total stomach tissue and has about 25 per cent of the total stomach capacity at about the 100th day of intra-uterine life. It then indicates a declining growth trend upto the 7th month of foetal age beyond which it starts gaining back again both in relative tissue weight and capacity. At about the close of the foetal term it accounts for about 37 per cent and 42 per cent, as against 56·65 per cent and 60·33 per cent at birth, of the total stomach tissue and capacity respectively.

After the calf is born its abomasum again starts losing in proportion to the total stomach both in tissue weight and capacity. As a result of this by the end of about a year it returns back to 16·07 per cent of the total stomach by its tissue weight and 17·47 per cent by its capacity as against the respective proportions of 13·35 per cent and 8·86 per cent of the adult.

Histologically, the abomasum also, has the usual four layers get distinguished progressively during foetal growth (Fig. 9). The serosa, muscularis, and submucosa elaborate with the growth of foetus as in case of rumen or reticulum. Of the fundic and pyloric regions the latter develops a thicker and more elaborate musculature than the former.

The submucosa remains cellular and blending with the lamina propria as the muscularis mucosae do not develop during the early foetal stages. During the later half of the foetal life, however, this gets evident and elaborates subsequently.

The mucosa remains quite simple, thin and indistinctly separated from the submucosa for want of a muscularis mucosae between the two during early foetal stages (Fig. 9·3 and 9·4). This, however, deepens considerably during the second half of the foetal life and elaborates by way of developing gastric folds that project into the lumen of the organ (Fig. 9.5 and 9.6). The developing gastric folds and the inner lining in between the folds gets profusely folded to accommodate the developing gastric glands. With the progress of time and by about the full term (Fig. 9.7 and 9.8) the muscularis elaborates considerably and the mucosa also deepens to contain a large number of gastric glands. These in the region of fundus develop parietal cells which are evidently seen in preparations from the newly born calf. No trace of keratinization could be seen in this organ at any stage of development.

A birds eye view about the comparative statement of the different stomach compartments during pre- and postnatal growth in case of buffalo can be had from table 8.

It is seen from table 8 that at about the 3rd month of foetal life the rumen has the maximum tissue weight and is followed by abomasum, omasum and reticulum in succession. While the reticular tissues always weighed lowest irrespective of the pre- or postnatal growth, the other three compartments, on the other hand, are seen changing and reversing their relative tissue weight positions several times with one another. The relationship of these compartments has also been graphically represented (Fig. 10).

The abomasum and omasum which change their relative positions during the 5th month of foetal life go back to their original relations during the 9th month of intra-uterine life to full term. By birth the abomasum gains the uppermost hand (about twice that of rumen) and is followed by rumen, omasum and reticulum and these proportions are maintained through the absolute milk feeding regime of the calf. However, the large differences between the abomasum and rumen are progressively narrowed down and from the time the calf takes to roughage feeding the rumen starts gaining the upper hand back again and weighs heaviest amongst all the stomach compartments. It then continues to gain in tissue weight in leaps and bounds so much so that by about the end of first year rumen, reticulum, omasum and abomasum make 55·31, 9·14, 19·48 and 16·07 per cent of the total stomach as against 58·42, 10·49, 17·74 and 13·35 per cent of the adult respectively.

TABLE 8

Showing the relative statement of different compartments of stomach at different stages of pre- and postnatal growth in buffalo.

Stage of development	Tissue weight as % of total stomach				Capacity as % of total stomach			
	Rumen	Reticulum	Omasum	Abomasum	Rumen	Reticulum	Omasum	Abomasum
				Prenatal Stages				
3rd month	72·00	4·00	8·00	16·00	...	...	...	...
4th month	48·48	10·10	18·69	22·73	46·22	18·89	9·70	25·19
5th month	43·82	16·69	20·12	19·37	68·88	9·66	4·89	16·57
6th month	44·23	13·42	24·69	17·65	74·74	8·20	3·93	13·12
7th month	40·82	14·80	27·98	16·40	72·35	7·35	4·10	16·20
8th month	35·11	14·78	27·19	22·92	70·43	7·12	3·49	18·96
9th month	35·37	14·52	23·11	27·00	60·59	7·83	2·57	29·01
10th month	40·92	9·27	12·88	36·93	48·34	7·58	2·01	42·07
				Postnatal Stages				
Birth to 5 days	28·66	6·39	8·30	56·65	32·18	6·24	1·25	60·33
6 to 15 days	29·92	6·45	8·02	55·61	43·66	4·52	1·13	50·69
16 to 30 days	38·93	7·03	8·55	45·49	50·95	5·50	1·79	41·76
31 to 60 days	43·24	6·50	13·75	36·51	61·63	3·88	1·68	32·81
61 to 120 days	49·85	8·54	16·68	24·93	71·99	1·89	1·96	24·16
121 to 515 days	55·31	9·14	19·48	16·07	79·98	1·15	1·40	17·47
Adult	58·42	10·49	17·74	13·35	88·13	0·93	2·08	8·86

The capacity measurements, both during pre- and postnatal life in buffalo also indicate almost a similar trend (Fig. 11) with the difference that omasum instead of reticulum has the least capacity except when calf becomes an effective ruminant and the omasum gains over reticulum. It may, therefore, be noted that at birth, rumen, reticulum and omasum combinedly are smaller than the abomasum but these compartments develop relatively more rapidly after birth.

With regard to dispositional details the abomasum is seen as a seccular organ situated immediately behind the diaphragm with its long axis directed slightly obliquely and dorso-ventrally. The rumen, reticulum and omasum are of appreciable size at birth (Fig. 6.1) and their development depends upon the ingestion of roughages. Almost similar view is held by Benzie and Phillipson (1957), who also link the ingestion of solid food with the development of these compartments in case of kids, lambs and calves.

During the absolute suckling stage of calf the abomasum also lies almost on the left side of the median line of the abdominal cavity (Fig. 6.1). As the reticulum and omasum start gaining importance with the ingestion of roughage, the abomasum moves away from the diaphragm caudally and to the right of the median plane. Its final position, however, is not attained until about 4 to 5 months of age by when the animal starts eating large quantities of roughage. In general the abomasum increases at a much slower pace than the rumen and finally it comes to lie on the right side of the median line in the epigastric region of the abdominal cavity. A similar dispositional shift has also been reported in case of growing kids, lambs and calves by Benzie and Phillipson (1957) on the basis of X-ray studies.

Histologically, all the four stomach compartments elaborate almost on common lines with very few specific differences which have already been discussed with respective compartments.

The Stomach Contents

A consolidated account of the distribution of wet ingesta in different compartments of the stomach, as come across at different stages of postnatal growth in this study, will not be out of place and is summarised in table 9 and graphically represented in figure 12.

TABLE 9

Showing the percentage of total wet-ingesta in different compartments of stomach at different stages of postnatal growth in buffalo.

	Age in days						
	0—5	6—15	16—30	31—60	61—120	121—515	Over 5 Yrs.
Total gut ingesta (gm)	820·25	1067·54	1463·90	2805·20	6412·80	18908·40	84913·68
Total gut ingesta as per cent of body weight	2·88	3·55	4·17	6·42	10·79	15·07	17·57
Oesophagus	0·00	0·00	0·00	0·00	0·00	0·00	0·01
Rumen	1·65	4·05	8·61	44·06	68·11	80·21	76·60
Reticulum	0·43	0·75	0·70	0·87	1·13	1·09	1·31
Omasum	0·15	0·52	0·67	1·94	2·18	2·94	6·31
Abomasum	18·74	19·72	23·09	12·90	6·11	2·54	2·13
Intestines (Details reported in Part II)	79·03	74·96	66·93	40·23	22·47	13·22	13·64
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00

It is seen from table 9 that while the total gut contents constantly increase with age (2·88% of body weight at about birth to 17·57% at maturity) both in absolute weight and weight in relation to body, their further apportionment to different sections of the gut reveals an interesting feature. During the early milk feeding regime abomasum has the maximum contents and the other stomach compartments contain only nominal amounts of ingesta.

The above sequence is maintained through the absolute milk feeding stage of the calf which may be considered to last for about a month or so. At the close of this stage and the beginning of the second month, the rumen starts gaining contents and by about one year's of age it holds about 80% of the total gut ingesta as against 76.6 per cent of the adult. It is followed by omasum, abomasum and reticulum which contain about 3%, 2·5% and 1% ingesta as against 6%, 2% and 1% of adult respectively.

The presence of ingested fluids in the fore stomach compartments, during the early milk feeding stages, come across in this study, appears to be erroneous and inconsistent with the physiological needs as the normally suckled fluids are not supposed to enter them but reach the abomasum after by passing the rumen, reticulum and omasum. Almost similar situations have also been reported by Benzie and Phillipson (1957) in case of growing kids, lambs and calves on the basis of their radiographic observations. They are of the opinion that this might happen in some animals as a rule or there could be a back flow of ingesta from the abomasum to the omasum and also to the reticulo-rumen.

SUMMARY AND CONCLUSIONS

Observations on the development of digestive system based on 150 foetuses and 35 calves of buffalo indicated that the roof of buccal cavity is derived from the transpalatine processes of maxilla while its floor is contributed by the first pair of visceral arches of embryo. Other associated structures develop as evaginations of the oral cavity. Cheeck papillae and the ossified gum cores develop towards the close of foetal life. The tongue elaborates with the growing snout and the different papillae develop towards the close of gestation.

The oesophagus, represented by a short wide membraneous tube in the beginning, grows in length with the straightening of the foetal posture and neck. The basal cells of the mucosal epithelium have cuboidal shape with oval nuclei and are covered with a single layer of squamous cells in the beginning. These grow in number with age of foetus and develop a keratinized border at the close of the full term. The oesophageal groove is also laid down quite early in life. It develops and elaborates from the invaginating reticular walls and the concentration of muscle fibres into them with the growth of foetus and by about full term it is completely formed.

The relative development and the dispositional shifts, which the stomach compartments make during the pre- and postnatal growth, are quite interesting. The heaviest rumen at 3rd month of foetal age is followed by abomasum, omasum and reticulum. They are seen changing and reversing their relative tissue weight positions several times with each other both during pre- and postnatal growth. The reticulum, however, abstains from these changes and uniformly maintains the lowest position althrough. Almost a similar trend is exhibited by them in respect of capacity also. At birth rumen, reticulum and omasum combinedly are smaller than the abomasum but these compartments develop more rapidly when the calf takes to roughage eating.

During very early stages of foetal growth all the four stomach compartments, some of which may not even be clearly marked out, lie in a cradio-caudal straight line. Sometime during the 3rd month of foetal life, the different compartments start reorienting themselves with regard to their relative positions as a result of differential growth and their straight line continuity is lost. Finally the stomach complex turns clockwise through 90° on its longitudinal axis and then rotates on its transverse one at the point of oesophageal attachment to 180° such that its transverse axis, which was almost horizontal to start with, gets vertically directed and the original longitudinal axis is completely reversed and by the 4th month of gestation the different compartments get topographically reoriented.

At birth and during the absolute milk feeding regime of the calf the abomasum also lies almost on the left side of the median plane of the abdominal cavity. As the forestomachs start gaining importance with the ingestion of roughages the abomasum moves away from the diaphragm gradually and to the right to attain the final position by about the 4th or 5th month of postnatal life when the calf starts eating large quantities of roughages.

The rumen papillae and the reticullar ribs are seen growing from 8th month of gestational life of the calf and get quite numerously disposed by the full term. After birth the papillae continue to grow in size, elaborate in form and develop papillary bodies as the calf takes to roughage eating. The colour of the mucosa of forestomachs, which is generally pale-white at birth, changes through various shades of yellow and brown to dark brown in colour depending upon the milk feeding regime and its transition to the roughage eating one.

Histologically, the walls of the different stomach compartments have the blue prints of all the layers true of an adult during early development which progressively elaborate with the growth of foetus and calf. The squamous cell layers which line the forestomach compartments from within are simple and fewer during the earlier stages, grow to get numerous by about the close of gestational life. and start receding back again after the calf is born and takes to roughage eating. Elaboration of the papillary bodies also appears to take place under the influence of roughage consumption and the V.F.A. production.

The distribution of ingesta in the different compartments of stomach through postnatal stages, indicates that during the early milk feeding regime abomasum has the maximum contents as against the forestomachs which contain only nominal amounts. As the calf grows the rumen starts gaining contents and soon supercedes abomasum to hold about 80 per cent of the total gut contents at one year age as against 77 per cent of the adult.

EXPLANATION OF FIGURES

Fig. 1: Showing collection of foetuses and the handling of buffalo calves for study.

Fig. 1.1: The city slaughter house Agra from where most of the foetuses were collected.

Fig. 1·2: An anaesthesised calf on operation table to be sacrificed for the study.

Fig. 1.3: A biopsy punch used for taking the rumenal and omasal samples for the study of papillary growth.

Fig. 2: Showing the handling of buffalo Foetuses and growing calves.

Fig. 2.1: Sterioscopic binocular used for dissecting small foetuses.

Fig. 2.2: A 41-day stage
Fig. 2.3: A 45-day stage
Fig. 2.4: A 60-day stage
Fig. 2.5: A 75-day stage
Median longitudinal sections of the early foetuses to show the progressive development of the buccal cavity and tongue (T).

Fig. 2.6: A 60-day foetus dissected under binocular to show the developing intestine (I).

Fig. 2.7: A 50-day foetus dissected under binocular to show the extensive nature of the liver (L).

Fig. 2.8: A 60-day foetus showing the yolk stalk (Y.S.) intestine (I) and stomach (S).

Fig. 2.9: A-day old calf dissected to show the oesophagus (O) Rumen (Rn), Reticulum (Rm) Omasum (Om) Abomasum (Ab), Intestine (I) and Rectum (R) and their location in the abdominal cavity.

Fig. 4: Showing the histological development of oesophagus and the oesophageal groove in buffalo.

Fig. 4.1: T.S. through the oesophageal wall of a 50-day foetus. Note the developing muscle layers, the blending submucosa and lamina propria with a single layer of squamous cells.

Fig. 4.2: T.S. through the epithelium of oesophageal mucosa. Note the cuboidal cells of the stratum basale with oval nuclei marked by arrows.

Fig. 4.3: T.S. through the oesophageal wall of a 75-day foetus. Note the increased layers of squamous cells.

Fig. 4.4: T.S. through the oesophagus of a 150-day foetus. Note the increased layers of squamous cells and the foldings of mucosa.

Fig. 4.5: T.S. through the oesophageal wall of a-day old calf. Note the disposition of muscle layers, loose connective tissue of the submucosa and the keratinised mucosa.

Fig. 4.6: T.S. through the oesophageal groove of a 65-day foetus. Note the developing pillars with muscles and covered with squamous cells.

Fig. 4.7: T.S. through the oesophageal groove of a 150-day foetus. Note the muscled pillars of the miniature groove.

Fig. 4.8: T.S. through the oesophageal groove of a full term calf. Note its elaborated nature.

Fig. 5: Showing the development of stomach compartments during foetal growth (41-310 days) in buffalo. (Figs. 5.1 to 5.12 posterio-ventral and 5.13 to 5.24 posterio-dorsal view (Size in relation to mm. scale alongside them.)

Fig. 5.1: A 41-day stage. Note the enlarged reticular portion (2) attached to oesophagus with anterior rumenal (1) and posterior omaso abomasal buldge (3).

Fig. 5.2: A 43-day stage
Fig. 5.3: A 45-day stage
Fig. 5.4: A 50-day stage
Fig. 5.5: A 60-day stage
Fig. 5.6: A 65-day stage
Note the progressively enlarging rumen (1) and the differenciating reticulum (2) omasum (3) and abomasum (4).

Fig. 5.7: A 70-day stage
Fig. 5.8: A 75-day stage
Fig. 5.9: A 80-day stage
Fig. 5.10: A 85-day stage
Fig. 5.11: A 90-day stage
Fig. 5.12: A 100-day stage
Note the fast growing rumen (1) and the ruminal grooves. The topographical rearrangement of the different compartments is also note worthy.

Fig. 5.13: A 110-day stage
Fig. 5.14: A 120-day stage
Fig. 5.15: A 130-day stage
Fig. 5.16: A 140-day stage
Fig. 5.17: A 150-day stage
Fig. 5.18: A 175-da, stage
Note the relative growth of the different stomach compartments. The insignificant nature of abomasum is note worthy.

Fig. 5.19: A 200-day stage. Note the relative size of the four compartments. Rumen (1), Reticulum (2), Omasum (3), and Abomasum (4).

Fig. 5.20: A 225-day stage
Fig. 5.21: A 250-day stage
Fig. 5.22: A 275-day stage
Fig. 5.23: A 300-day stage
Fig. 5.24: A 310-day stage
Note the fast elaborating abomasum (4) during the last phases of the intrauterine life.

Fig. 6: Showing the development of rumen and ruminal papillae during postnatal growth in buffalo.

Fig. 6.1: Rumen (Rn), Reticulum (Rm), Omasum (Om) and Abomasum (Ab) of a-day old calf.

Fig. 6.2: Rumen (Rn) of a-year old calf. Note the spleen (S) closely associated with it.

Fig. 6.3: Rumen wall of a-day old calf showing the densely populated conical papillae.

Fig. 6.4: The same as Fig, 6.3, magnified.

Fig. 6.5: Rumen wall of a 20-day calf showing finge like papillae.

Fig. 6.6: The same as Fig. 6.5, magnified.

Fig. 6.7: Rumen wall of a 50-day calf with foliate papillae.

Fig. 6.8: Rumen wall of a 105-day calf with foliate papillae.

Fig. 6.9: Rumen wall of a-year old calf with foliate papillae.

Fig. 6.10: Rumen wall of an adult buffalo with foliate papillae.

Fig. 6.11: The same as Fig. 6.10, magnified.

Fig. 7: Showing the histological development of rumen and reticulum in buffalo.

Fig. 7.1: T.S. through the rumen wall of 50-day foetus. Note the undifferenciated wall layers and the low squamous cell layers.

Fig. 7.2: T.S. of rumen wall of a 75-day foetus passing through the developing pillars. Note the invaginating walls and the concentration of muscle fibres into them (marked by arrows).

Fig. 7.3: T.S. through rumen wall of a 150-day foetus. Note the prominently developed muscle and submucosal layers and the developing papillae as the conical outgrowths of the basal layer into the squamous layer (marked by arrows).

Fig. 7.4: The same as 7.3. The growing papilla magnified. Note the lamina propria making core of the papilla.

Fig. 7.5: T.S. through rumen wall of a 300-day foetus. Note the highly developed muscle zone and the undifferenciated layers of squamous epithelium with papillae growing into them.

Fig. 7.6: T.S. through the ruminal papilla of a 5-day calf. Note the papillary bodies with lamina propria core.

Fig. 7.7: T.S. through rumen wall of a 5-day calf. Note the bifurcating papillae (marked by arrows).

Fig. 7.8: The same as Fig. 7.6, magnified to show 3 to 4 layers of cells in the stratum corneum.

Fig. 7.9: T.S. through the reticular wall of a 50–day foetus. Note the comparatively thicker muscular zone and the squamous cell layer than that of the rumen of the same age (Fig. 7.1).

Fig. 7.10: T.S. through the reticular wall of a 150–day foetus. Note the wavy disposition of the stratum basale marked by arrows.

Fig. 7.11: T.S. through the reticular wall of a 220–day foetus. Note the elaborating muscular zone and the cup like feature of the growing reticular ribs.

Fig. 7.12: T.S. through the reticular wall of a full term foetus. Note the reticular ribs with swallen tips covered by squamous cells.

Fig. 8: Showing the Histological Development of Omasum in Buffalo.

Fig. 8.1: T.S. through the omasal wall of a 50–day foetus. Note the thickened musculature towards the omasal pillar marked by arrow and the growing laminae with a wide core.

Fig. 8.2: T.S. through the omasal wall of a 100–day foetus. Note the profuse growth of various order laminae with reduced core and squamous cell layers.

Fig. 8.3: T.S. through the omasal wall of a 250–day foetus. Note the developing muscle in the core of laminae.

Fig. 8.4: T.S. through the omasal wall of a full term foetus. Note the increased squamous cell layers and the development of papillary bodies.

Fig. 8.5: T.S. through the omasal wall of a 5–day old calf. Note the extensive growth of papillary bodies on the laminae containing muscles and vessels in their core.

Fig. 8.6: }
Fig. 8.7: } The same as specimen of Fig. 8.5 printed negatively and positively to indicate the profuse development of the laminae and the papillary bodies on them.

Fig. 9: Showing the Histological development of abomasum in buffalo.

Fig. 9.1: T.S. through the abomasum of a 50–day foetus. Note the developing gastric folds.

Fig. 9.2: The same as figure 9.1, magnified to show the extensive lamina propria and the thick layer of muscularis.

Fig. 9.3: T.S. through the abomasum of a 100–day foetus. Note the further elaboration of the gastric folds. The muscularis mucosae is not yet developed.

Fig. 9.4: The same as figure 9.3, magnified. Note the elaborating mucosa.

Fig. 9.5: T.S. through the abomasal wall of a 250–day foetus. Note the developing muscularis mucosae.

Fig. 9.6: The same as figure 9.5, magnified to show the developing muscularis mucosae separating the cellular lamina propria from the subjacent fibrous submucosa.

Fig. 9.7: T.S. through the abomasal wall of a full term foetus. Note the strong muscularis, loose connective tissue of submucosa and almost fully developed mucosa.

Fig: 9.8: The same as figure 9.7, magnified to show the mucosa with gastric glands.

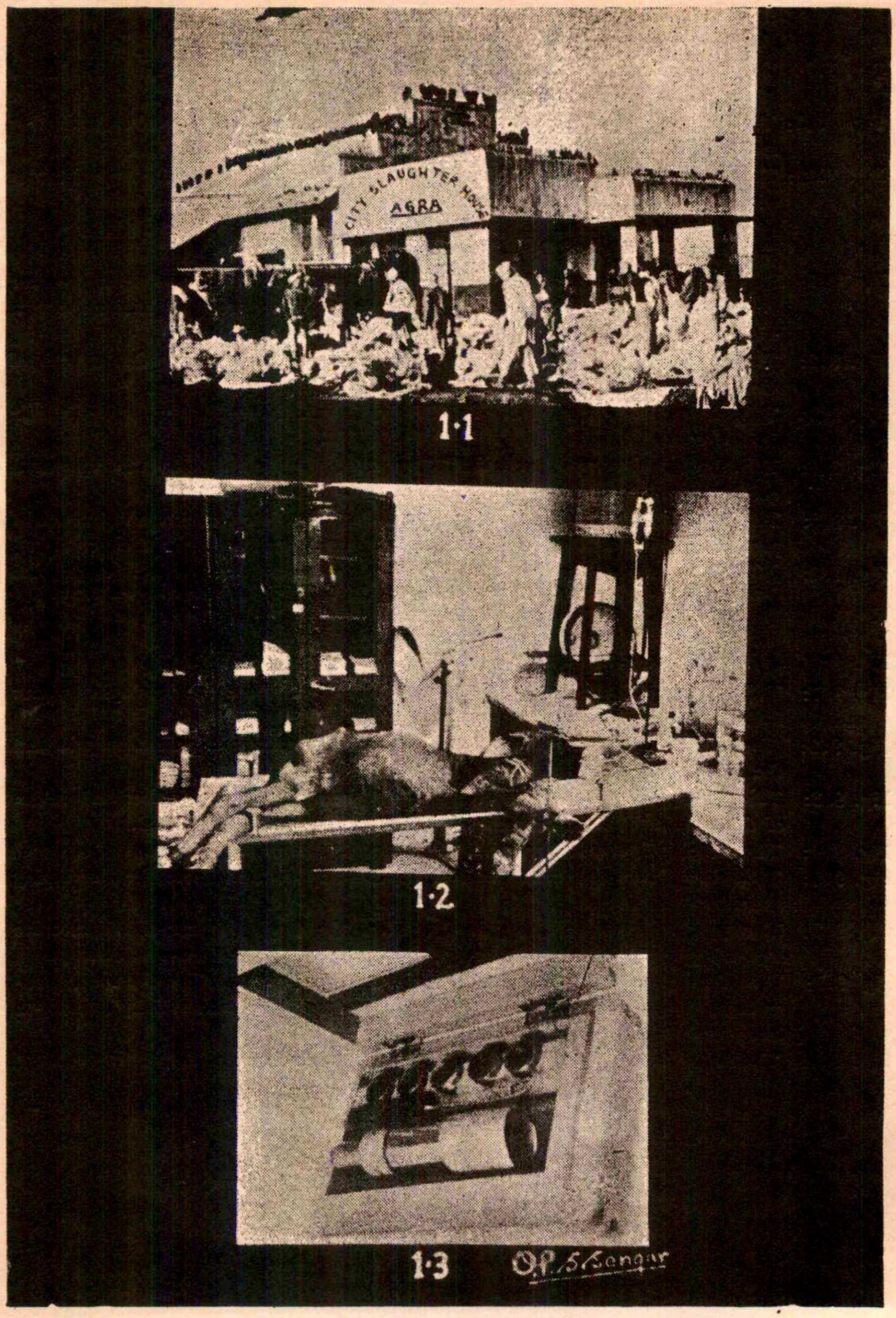


Fig. 1. Showing collection of Foetuses and the handling of buffalo Calves for Study.

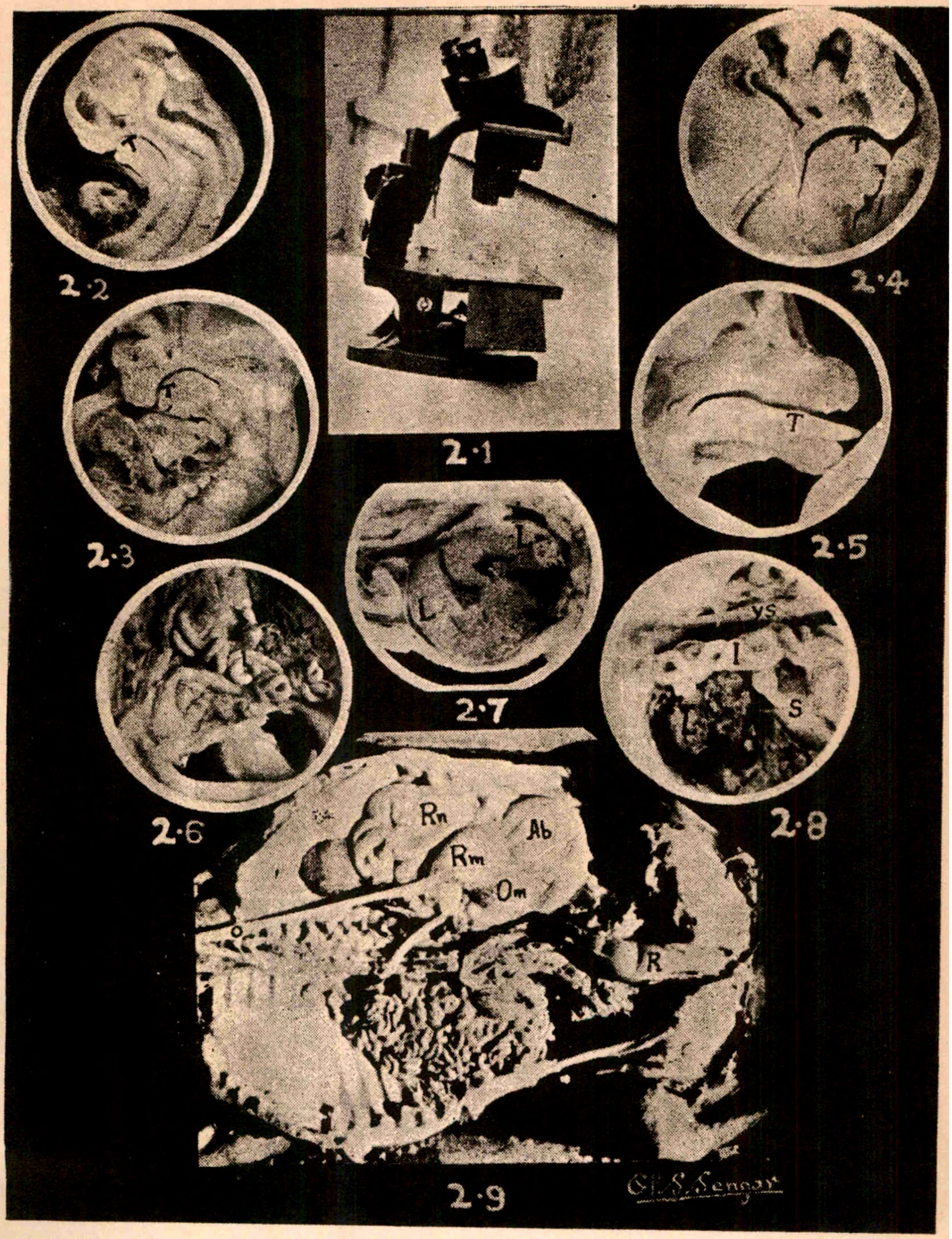
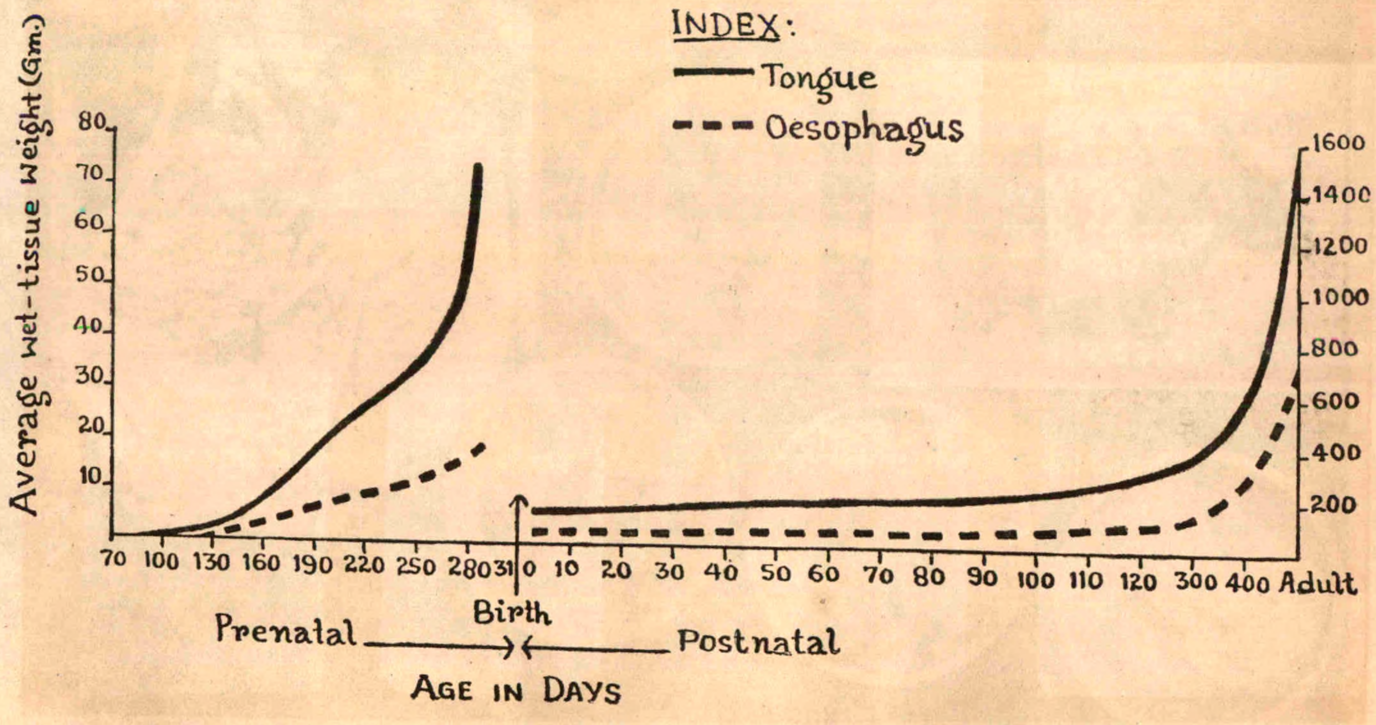


Fig. 2. Showing the handling of buffalo Foetuses and growing Calves.

FIG. 3: Showing the wet-tissue weight of tongue and oesophagus at different stages of pre-and postnatal growth in buffalo.



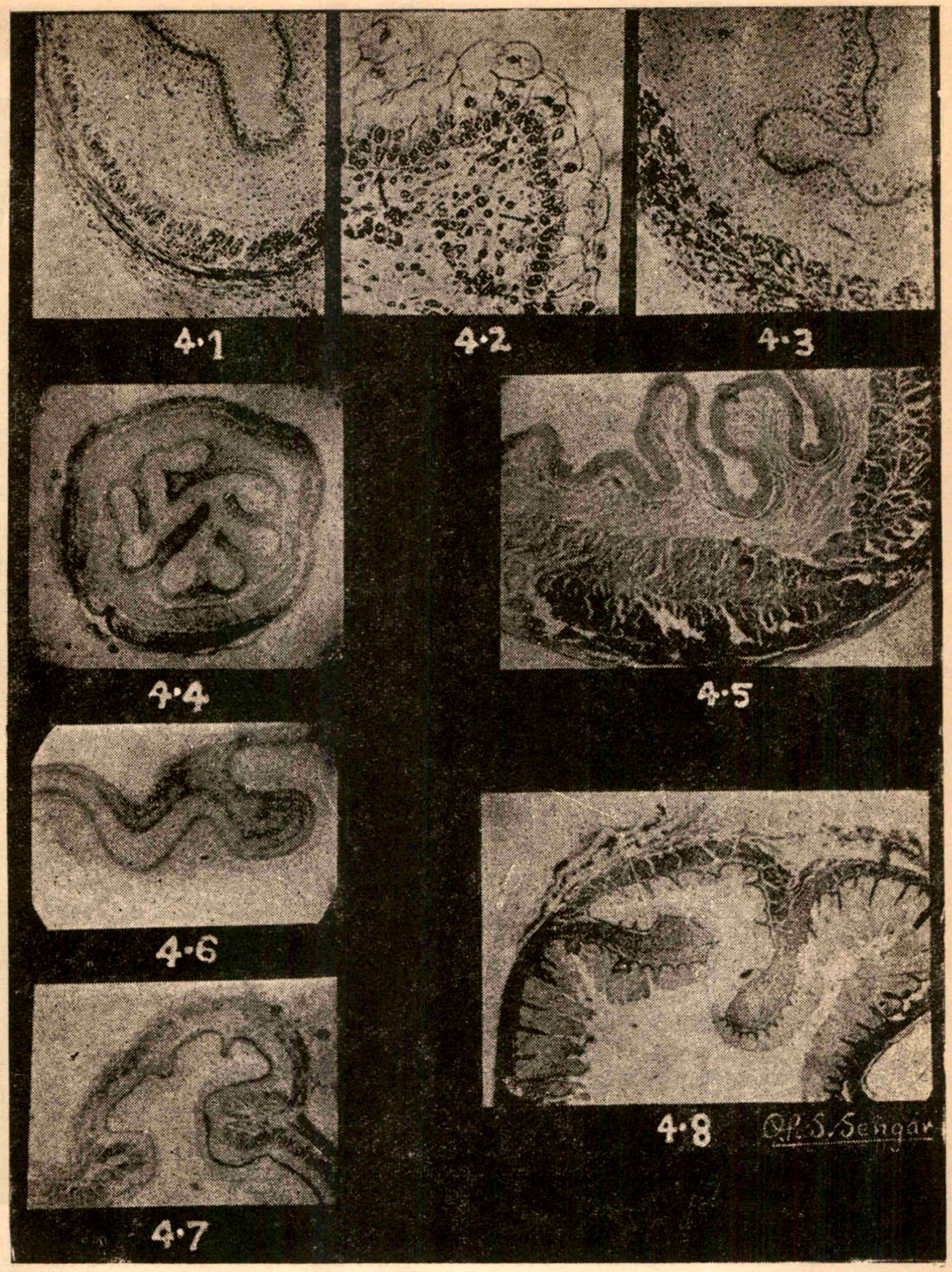


Fig. 4. Showing the Histtological Development of Oesophagus and Oesophageal Groove in Buffalo.

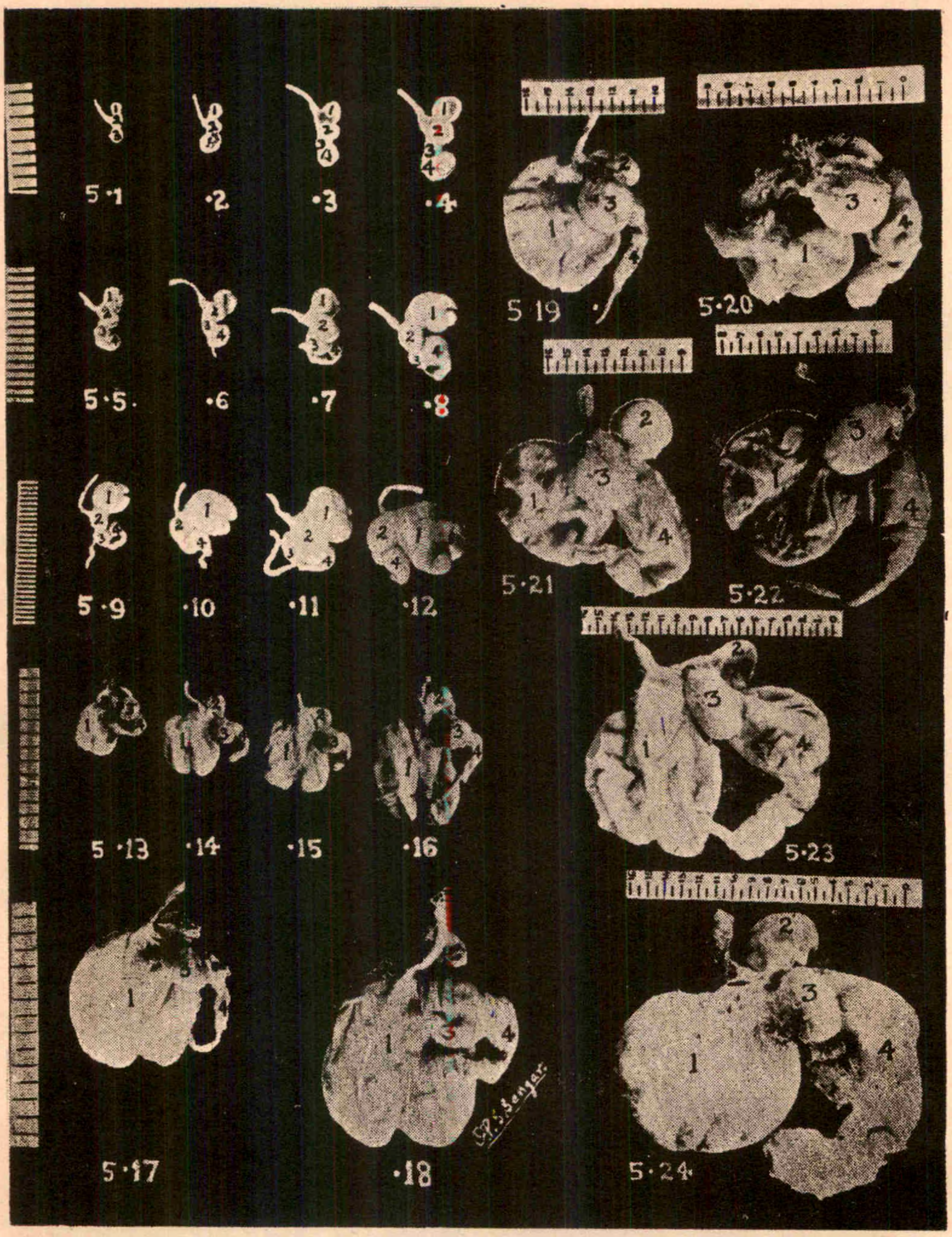


Fig. 5. Showing the Development of Stomach compartments during Foetal Growth (41–310 days) in Buffalo. (Figs. 5·1 to 5·12 posterio-ventral and 5·13 to 5·24 posterio-dorsal view. Size in relation to mm. scale alongside them.)

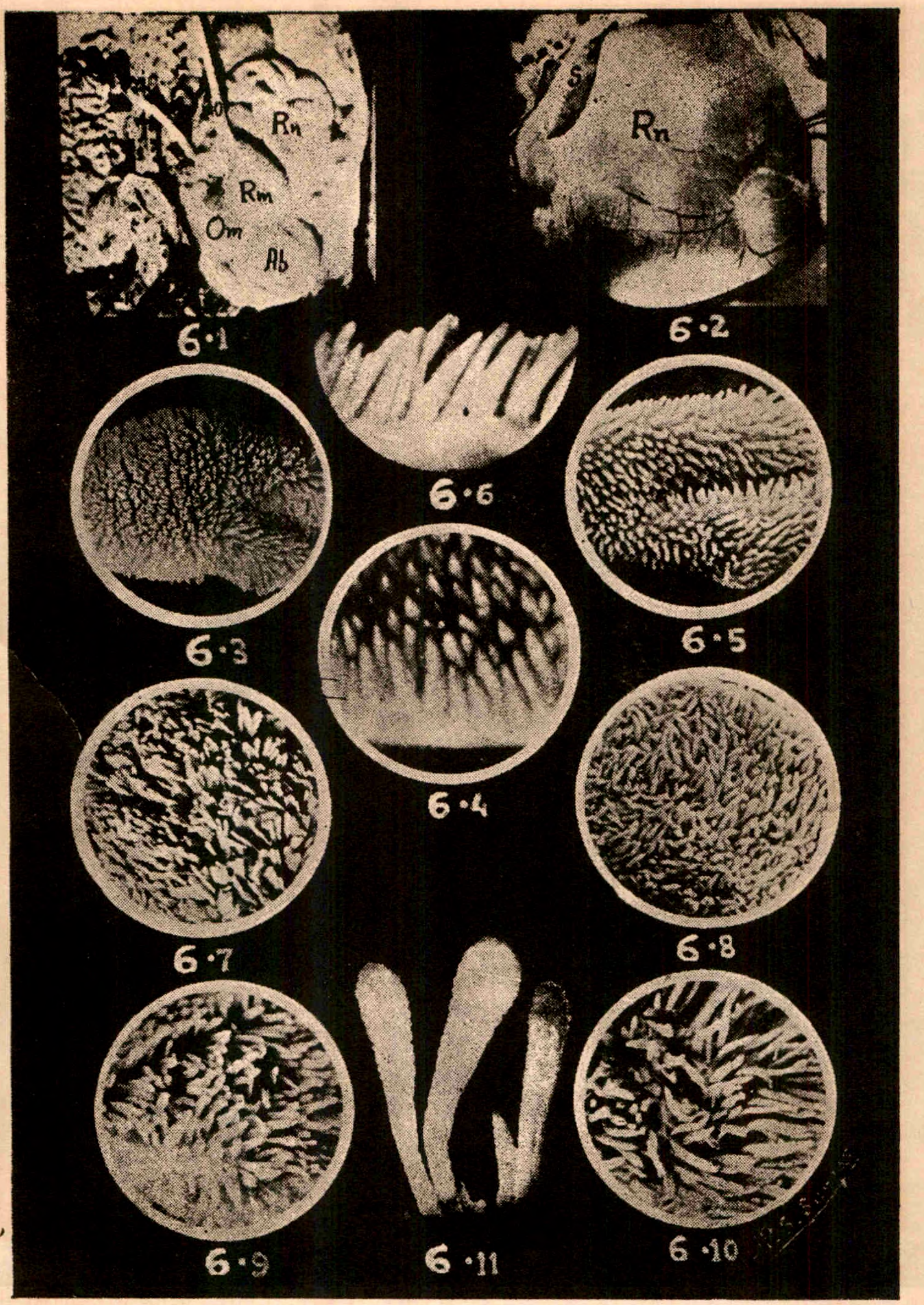


Fig. 6. Showing the Development of Rumen and Ruminal Papillae during Postnata Growth in Buffalo.

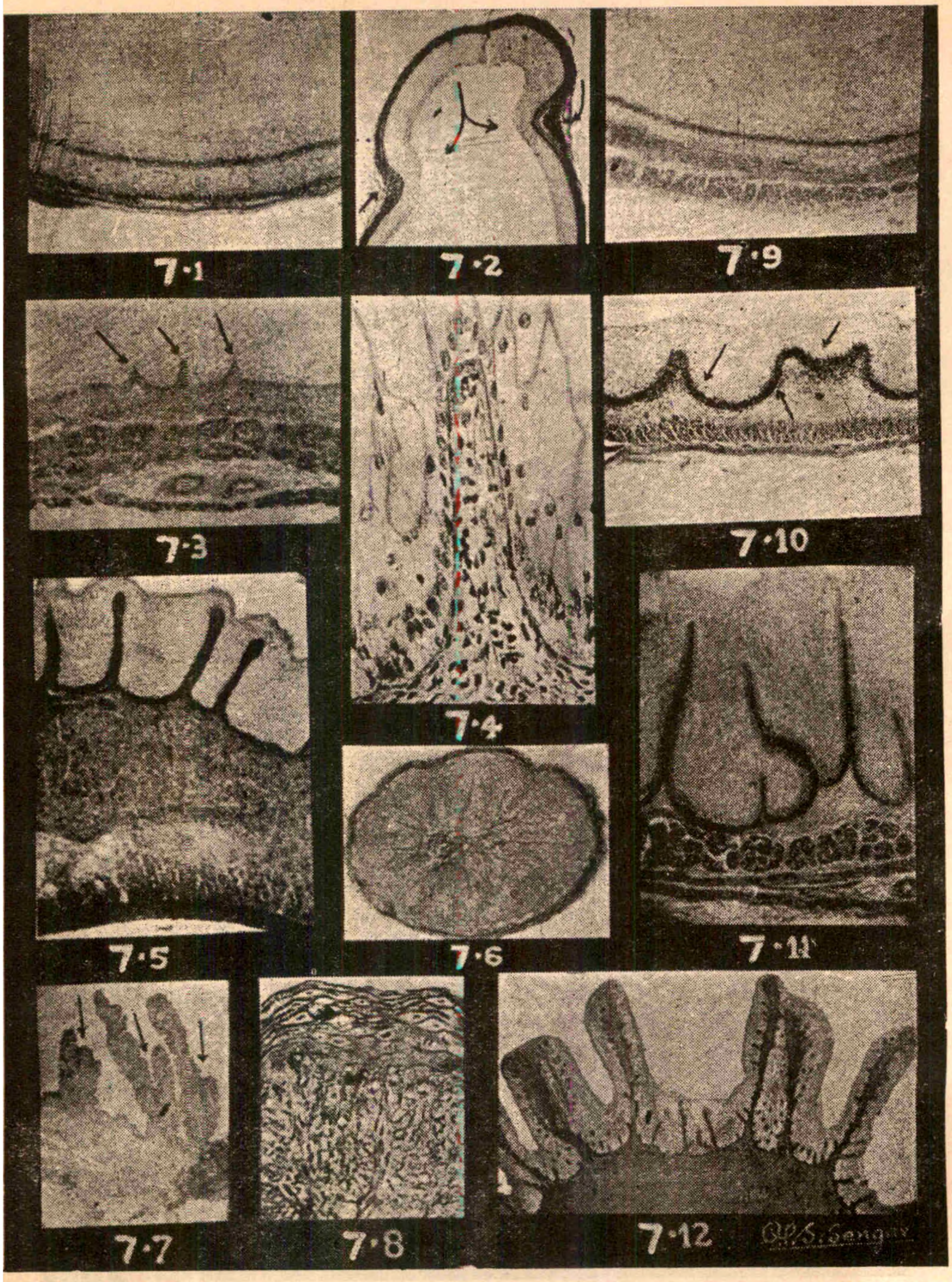


Fig. 7. Showing the Histological Development of Rumen and Reticulum in Buffalo.

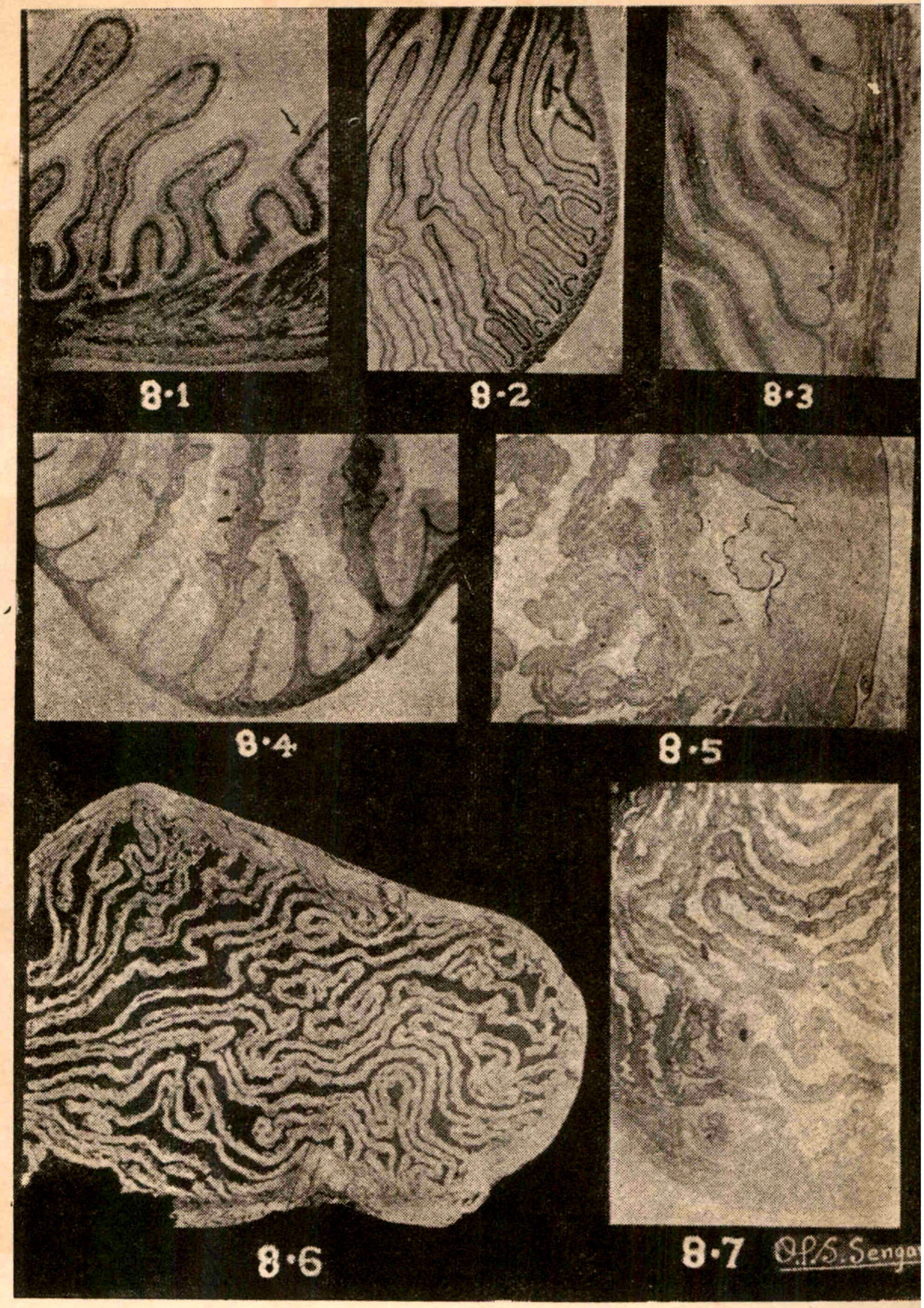
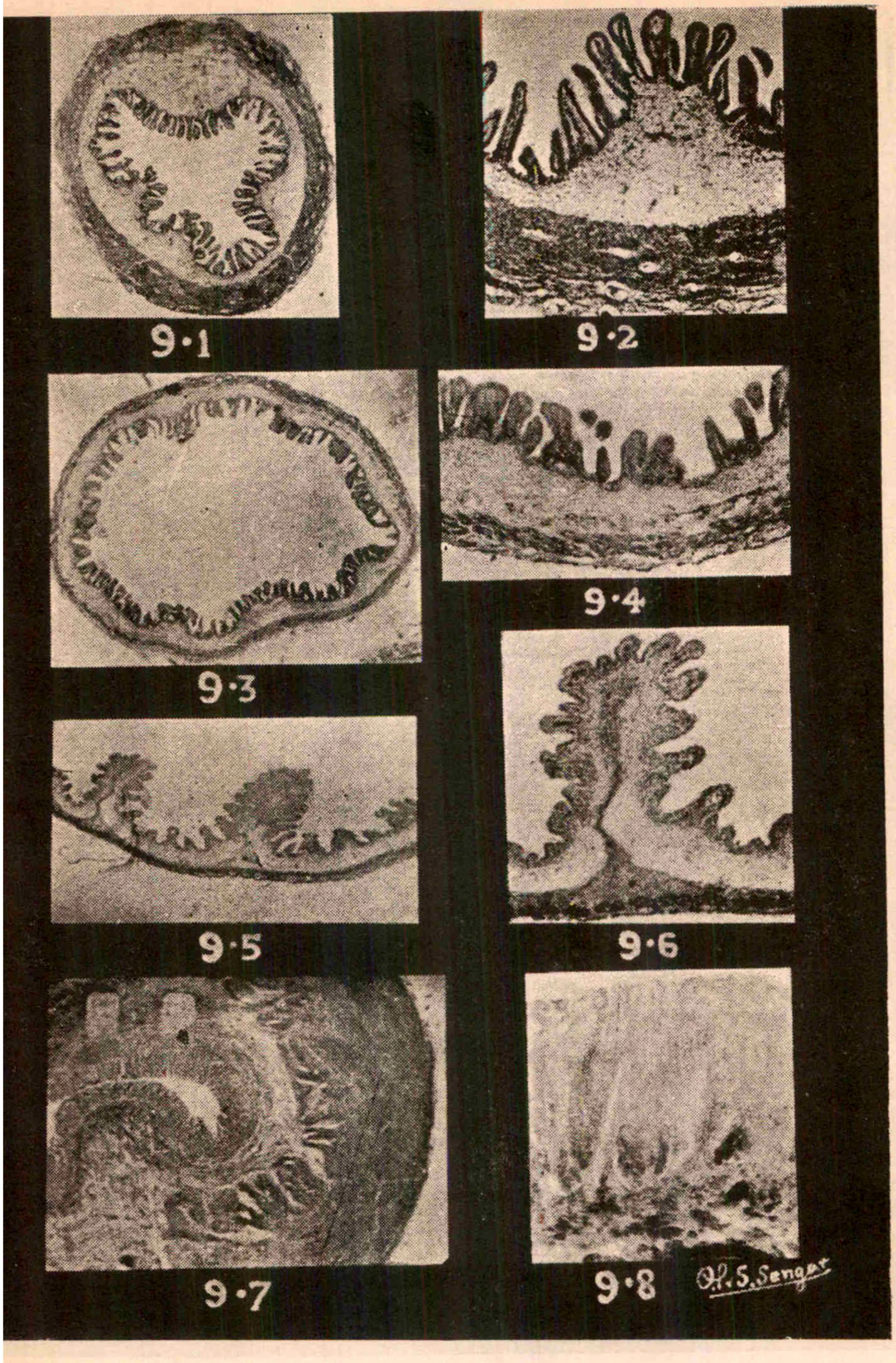


Fig. 8. Showing the Histological Development of Omasum in Buffalo.


9·1 9·2 9·3 9·4 9·5 9·6 9·7 9·8

9. Showing the Histological Development of Abomasum in Buffalo.

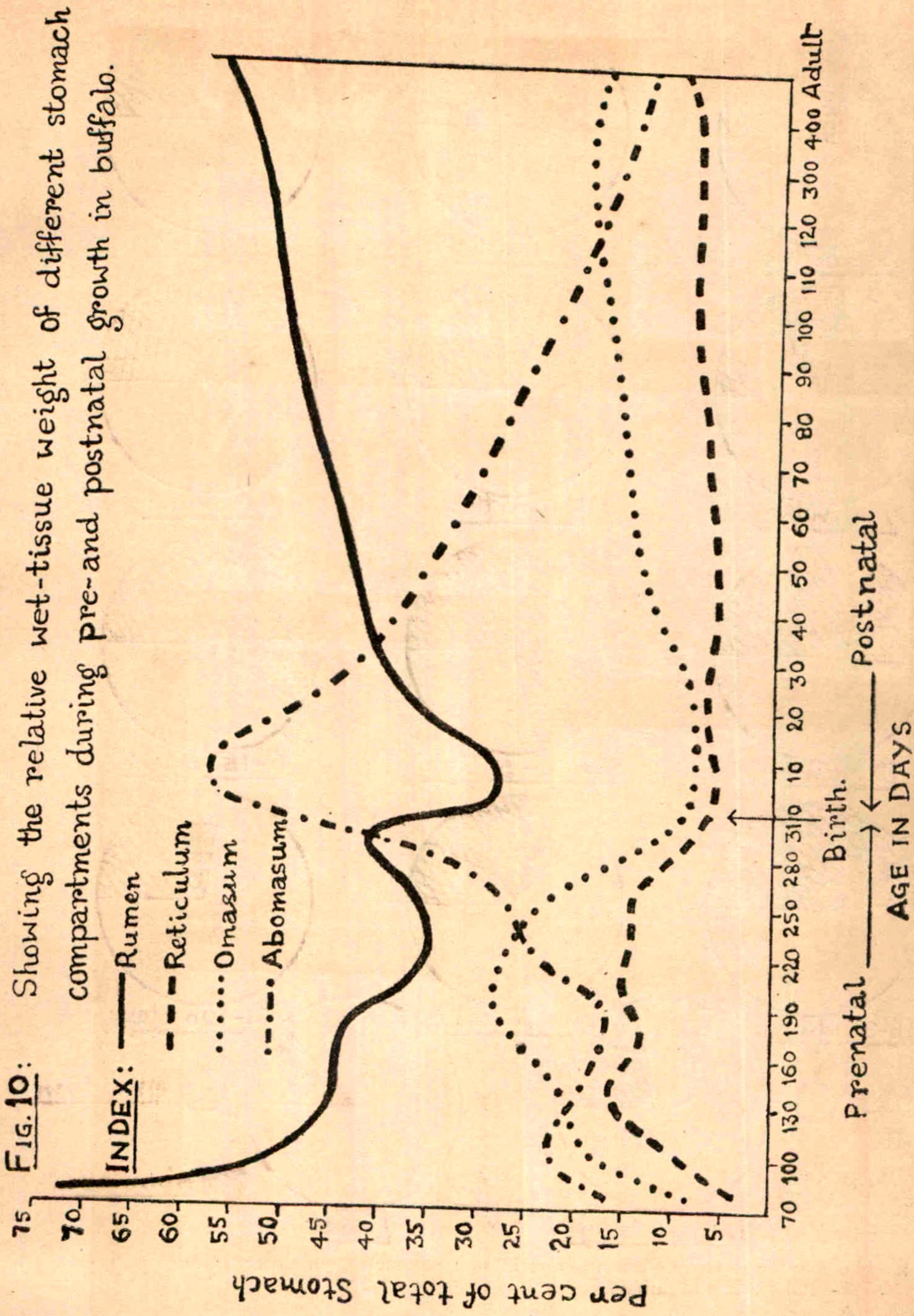
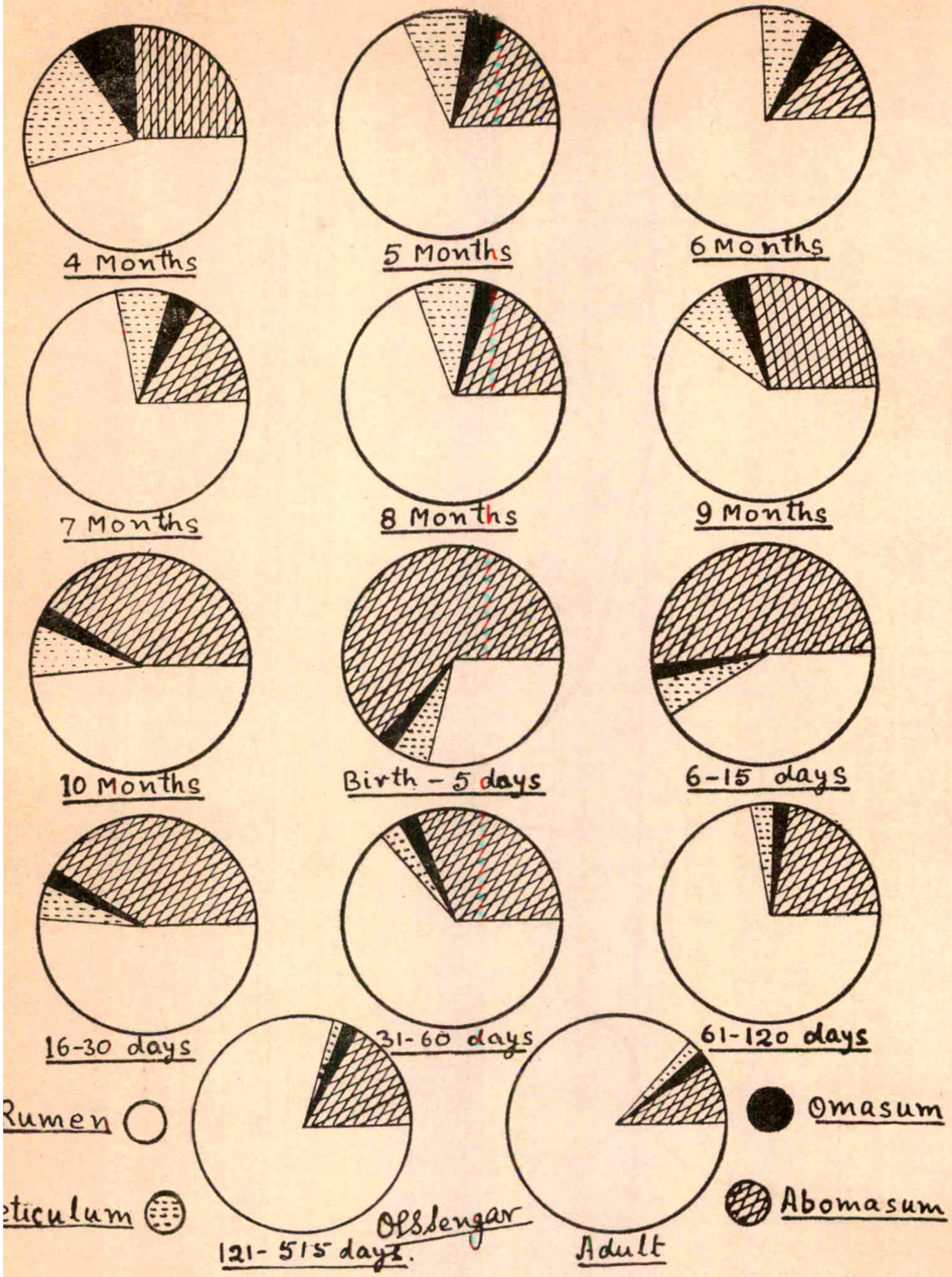


Fig. 10: Showing the relative wet-tissue weight of different stomach compartments during pre-and postnatal growth in buffalo.



ig. 11. Showing the Relative Capacity of Different stomach Compartments during Pre-and Postnatal Growth in Buffalo.

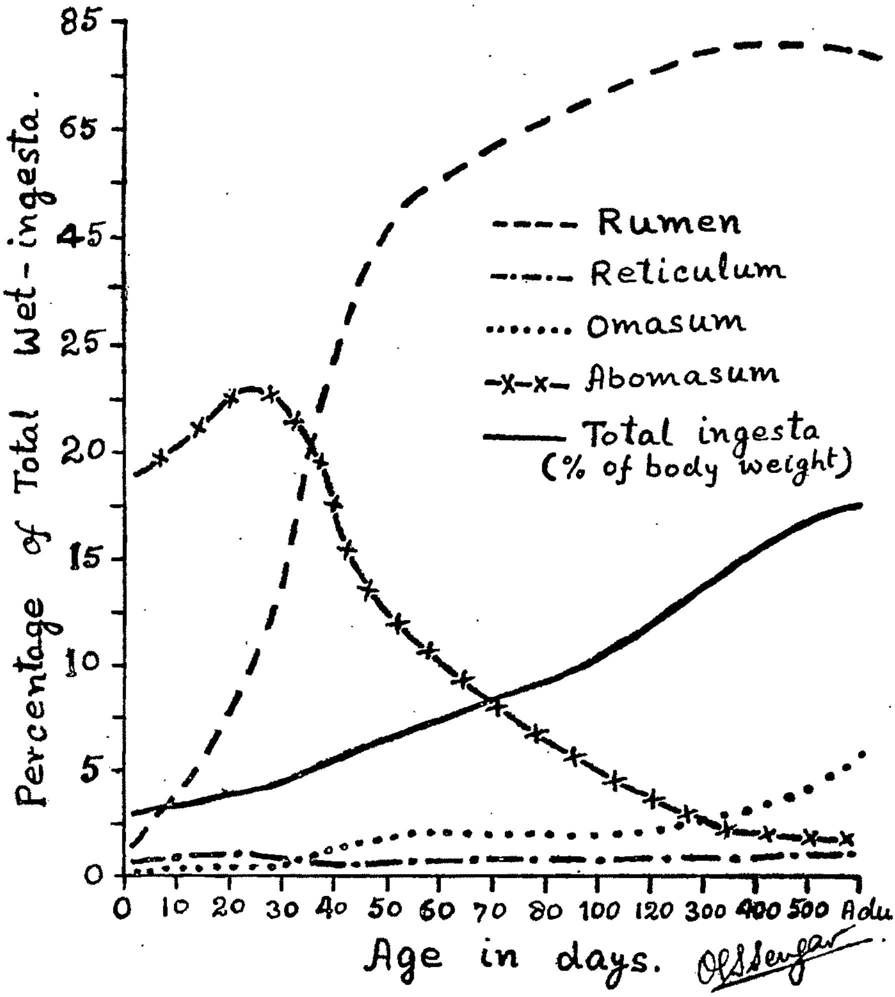


Fig. 12. Showing the Percentage of total Wetingesta in different Compartments of the Stomach at different Stages of Postnatal Growth in Buffalo.

PART II

DEVELOPMENT OF INTESTINE AND ACCESSORY DIGESTIVE GLANDS IN BUFFALO *Bos bubalis* L.*

The intestine, which represents a long winding tube and connects the stomach to the anal opening, has received practically no attention of the people. It starts with a humble beginning and at the foetal age of about 50-60 days, it is represented by a short slender tube running along the yolk stalk and bent on itself several times (Fig. 1). It lies embedded in the liver mass from which it is hard to be separated (Fig. 1.1). The different segments of the intestine get distinguishable as early as two months of intra-uterine life (Fig. 1.2) and elaborate with the growth of foetus and approach of the full foetal term (Fig. 2).

The Small Intestine

The small intestine is the first portion of intestinal complex and includes duodenum, jejunum and ileum in succession which blend into one another without any morphological distinction between them. The detailed observations made on the growth measurements of small intestine are summarised in table 1.

TABLE 1

Showing the measurements of small intestine at different stages of pre- and postnatal growth in buffalo.

Stage of development	Linear measurements			Tissue weight measurements			
	Average (cm.)	% of total gut length	% of body length	Average (gm.)	% of total intestine	% of total gut	% of empty body weight
				Prenatal Stages			
2nd month	2·46	49·80	175·72	...	...	...	...
3rd month	25·76	76·94	677·89	1·11*	100·00*	78·71*	6·01*
4th month	78·42	83·86	1131·60	3·28	81·39	53·25	3·68
5th month	154·43	82·44	1244·40	8·31	73·02	34·35	3·03
6th month	323·92	82·58	1793·58	19·21	75·16	32·40	1·63
7th month	438·25	83·70	1947·78	34·40	71·40	30·34	1·48
8th month	539·33	83·80	1752·78	61·12	74·92	34·27	1·26
9th month	709·50	82·66	1756·19	158·80	83·49	50·25	1·95
10th month	789·75	80·92	1534·99	236·75	79·44	44·94	1·48
				Postnatal Stages			
Birth to 5days	897·00	79·60	1560·00	413·75	72·68	42·02	1·50
6 to 15 ,,	1305·00	80·06	2184·10	473·00	71·42	38·81	1·51
16 to 30 ,,	1562·50	79·58	2513·67	658·00	73·61	42·65	1·96
31 to 60 ,,	1967·67	81·65	3072·08	912·00	73·94	40·25	2·23
61 to 120 ,,	2043·00	80·14	2969·48	1230·00	73·64	35·97	2·33
121 to 515 ,,	2334·20	77·24	2802·16	1487·00	65·20	22·36	1·39
Adult	3043·88	75·42	2096·64	4011·64	60·59	16·54	1·01

* Inclusive of caecum, colon and rectum also.

From table 1, it is seen that the small intestine remains extremely small during early foetal stage and measures on an average about 2·5 cm. in length during the 2nd month of foetal life, which accounts for about 50 per cent of the total gut length. It has an allometric growth during the 3rd and 4th month of the intra-uterine life and then changes to the isometric one, in relation to total gut, for rest of the foetal age. However, as far as the tissue weights are concerned they have a declined proportional growth from early to late foetal life.

At about the close of foetal term it measures roughly about 8 metres in length and makes about 81, 80 and 45 per cent of the total gut length, total intestine tissue and total gut tissue weights respectively. At birth these values are further reduced down to roughly about 80, 73 and 42 respectively. During postnatal growth small intestine also maintaints uniform growth upto the adulthood. The proportional trend in respect of length and tissue weight, however, shows a decline towards the end of one year of age and so also in the adult.

It may, therefore, be interpreted to mean that a good portion of the proportionate length and the tissues of small intestine are developed by about the 4th or 5th month of postnatal growth. Then-onwards it continues to add both length and weight but at a proportionately reduced rate. At the age of about a year the small intestine measures about 28 times the body length (pin-shoulder) and 1·39 per cent of the body by tissue weight as against the respective figures of 21 and 1·01 for the adult respectively.

The Caecum

The caecum gets identified sometime during the 2nd month of foetal growth as a small diverticulum and marks the point of union of small intestine and colon. The detailed observations made on the measurements of caecum during the course of this investigation are contained in table 2.

From table 2, it can be seen that at about its inception, sometime during the 2nd month, the caecum accounts for abont 2 per cent of the total gut and 7 per cent of the body lengths. With the passage of time and growth of foetus its length increases in proportion to body length and decreases in relation to total intestine which indicates that the gut segments, other than caecum, gain faster in length than caecum.

By about the close of the foetal regime caecum measures on an average about 9 cm. in length which makes 0·9 per cent of the total gut and 17·16 per cent of the body length respectively. At this stage it has an average weight of about 6 gm. making about 2·1, 1·2 and 0·04 per cent of the total intestine, total gut and empty body weights respectively.

At birth the length proportions of caecum in relation to other gut segments are almost the same as during the last month of foetal life but the tissue weight proportions are relatively reduced. It maintains almost the same proportions as at birth upto 4 months of age and then increases to adulthood both in respect of total gut length, and weight proportions to total intestine, total gut and empty body.

TABLE 2

Showing the measurements of caecum at different stages of pre- and postnatal growth in buffalo.

Stage of development	Linear measurements			Tissue weight measurements			
	Average (cm.)	% of total gut length	% of body length	Average (gm.)	% of total intestine	% of total gut	% of empty body weight
			Prenatal Stages				
2nd month	0·10	2·02	7·14	...	...	...	...
3rd month	0·34	1·02	8·95	...	...	...	...
4th month	0·65	0·70	9·38	...	...	...	...
5th month	1·33	0·72	10·72	...	...	...	...
6th month	2·64	0·67	14·62	0·37	1·45	0·62	0·03
7th month	3·17	0.61	14.09	1·89	3·92	1·67	0·08
8th month	4·42	0·69	14·36	3·15	3·86	1·77	0·07
9th month	6·28	0·73	15·54	3·96	2·02	1·25	0·05
10th month	8·83	0·90	17·16	6·30	2·11	1·20	0·04
			Postnatal Stages				
Birth to 5days	10·13	0·90	17·62	9·40	1·65	0·95	0·03
6 to 15 ,,	12·98	0·80	21·72	11·90	1·94	1·06	0·04
16 to 30 ,,	16·12	0·82	25·93	15·30	1·71	0·99	0·05
31 to 60 ,,	18·78	0·78	29·32	19·40	1·57	0·85	0·05
61 to 120 ,,	21·10	0·83	30·67	28·80	1·72	0·84	0·05
121 to 515 ,,	34·70	1·15	41·66	125·00	5·48	1·88	0·12
Adult	47·00	1·16	32·33	547·40	8·27	2·26	0·14

The Colon

The colon which makes bulk of the large intestine measures only about 1·24 cm. in length, which accounts for about 25 per cent of the total gut length in a 45 day foetus. The detailed observations made on the measurements of developing colon are contained in table 3.

From table 3, it is seen that while the colon gains both in absolute length and tissue weight, it indicates an almost constant proportional length but the tissue weight proportions have a declining trend by about the full foetal term when it makes about 11·81 per cent of the total gut length, 9·48 per cent of the total intestine tissue, 5·36 per cent of total gut tissues and 0·18 per cent of the empty body as against the respective figures of 13·09, 17·48, 10·10 and 0·36 per cent of a day old calf.

TABLE 3

Showing the measurements of colon at different stages of pre- and postnatal growth in buffalo.

Stage of development	Linear measurements.			Tissue weight measurements			
	Average (cm.)	% of total gut length	% of body length	Average (gm.)	% of total intestine	% of total gut	% of empty body weight
			Prenatal Stages				
2nd month	1·24	25·10	88·57	...	...	...	...
3rd month	3·84	11·47	101·05	...	...	...	...
4th month	7·69	8·22	110·96	0·75*	18·61*	12·16*	0·84*
5th month	20·33	10·85	163·81	3·07*	26·98*	12·69*	1·12*
6th month	45·44	11·58	251·61	3·10	12·13	5·23	0·26
7th month	55·88	10·67	248·36	7·55	15·67	6·66	0·33
8th month	64·92	10·09	210·99	11·20	13·73	6·27	0·23
9th month	87·91	10·24	217·60	14·48	7·61	4·58	0·18
10th month	115·25	11·81	224·00	28·26	9·48	5·36	0·18
			Postnatal Stages				
Birth to 5days	147·50	13·09	256·52	99·50	17·48	10·10	0·36
6 to 15 ,,	231·17	14·18	386·90	110·00	17·98	9·77	0·38
16 to 30 ,,	300·33	15·30	483·16	156·00	17·45	10·11	0·46
31 to 60 ,,	330·83	13·73	516·52	222·00	18·00	9·80	0·54
61 to 120 ,,	389·40	15·27	565·99	294·00	17·60	8·60	0·55
121 to 515 ,,	530·60	17·56	636·97	456·00	19·99	6·85	0·43
Adult	787·24	19·51	542·25	1316·72	19·89	5·43	0·33

* Inclusive of caecum and rectum also.

During the postnatal growth the colon increases in length considerably both in absolute length and length in proportion to total gut. But such is not the case with tissue weights which show a gain in absolute values but the gains in proportion to the total digestive tract decline after the milk feeding regime of calf. The colon tissue weight as per cent of the total intestine, however, indicates an increasing trend indicating thereby that the colon does grow in relation to intestines but when considered for the gut as a whole in which the fast growing rumen also gets included, its proportionate growth indicates a declining trend.

The Rectum

Rectum, the last segment of intestine in particular and that of digestive tract in general is laid down quite early in development and is derived from the proctodeal invagination of the embryo. The detailed observations on the growth measurements of rectum are summarised in table 4.

TABLE 4

Showing the measurements of rectum at different stages of pre- and postnatal growth in buffalo

Stage of development	Linear measurements			Tissue weight measurements			
	Average (cm.)	% of total gut length	% of body length	Average (gm.)	% of total intestine	% of total gut	% of body weight
				Prenatal Stages			
2nd month	0·23	4·66	16·43	...	...	...	...
3rd month	0·82	2·45	21·58	...	...	...	...
4th month	2·20	2·35	31·75	...	...	...	...
5th month	3·88	2·07	31·26	...	...	...	...
6th month	6·41	1·64	35·49	2·88	11·26	4·87	0·25
7th month	8·38	1·60	37·24	4·34	9·01	3·83	0·19
8th month	11·53	1·78	37·47	6·11	7·49	3·43	0·13
9th month	21·56	2·52	53·37	12·97	6·82	4·11	0·16
10th month	24·63	2·53	47·87	26·72	8·97	5·08	0·16
				Postnatal Stages			
Birth to 5 days	26·50	2·35	46·09	46·62	8·19	4·73	0·17
6 to 15 days	29·33	1 80	49·09	53·00	8·66	4·71	0·18
16 to 30 days	31·05	1·58	49·95	64·60	7·23	4·19	0·19
31 to 60 days	33·33	1·38	52·04	80·00	6·49	3·53	0·19
61 to 120 days	33·66	1·32	48·92	117·60	7·04	3·44	0·22
121 to 515 days	49·50	1·63	59·42	212·80	9·33	3·20	0·20
Adult	59·12	1·46	40·72	745·12	11·25	3·07	0·19

From table 4, it is seen that during the 2nd month of foetal growth rectum measures about a quarter centimeter and accounts for 4·66 per cent of total gut length. It continues to grow in absolute length but declines as part of the total gut. By about the middle of foetal life it measures 6·41 cm. (1·64% of total gut length) and weighs 2·88 gm. by tissue weight, which makes 11·26, 4·87 and 0·25 per cent of the empty total intestine, total gut and body respectively.

During the second half of intra-uterine life of calf, it proportionately gains in length to account for about 2·53 per cent of the total gut length by about the completion of foetal term. Almost a similar trend is indicated in respect of the tissue weight in proportion to total gut and the trends remain almost the same after birth upto the milk feeding regime of calf. It then declines in respect of both length and tissue weight proportions to gut and accounts for 1·63 per cent of total gut length and 3·2 per cent of the total gut tissues at about one year of age as against 1·46 per cent and 3·07 per cent of adult respectively.

TABLE 5

Showing the relative statement of different segments of intestines at different stages of pre- and postnatal growth in buffalo.

Stage of development	Length as % of total gut				Tissue weight as % of total intestine			
	Small intestine	Caecum	Colon	Rectum	Small intestine	Caecum	Colon	Rectum
				Prenatal Stages				
2nd month	49·80	2·02	25·10	4·66	...	...	...	...
3rd month	76·94	1·02	11·47	2·45	100·00*	...	...	...
4th month	83·86	0·70	8·22	2·35	81·39	...	18·61**	...
5th month	82·44	0·72	10·85	2·07	73·02	...	26·98**	...
6th month	82·58	0·67	11·58	1·64	75·16	1·45	12·13	11·26
7th month	83·70	0·61	10·67	1·60	71·40	3·92	15·67	9·01
8th month	83·80	0·69	10·09	1·78	74·92	3·86	13·73	7·49
9th month	82·66	0·73	10·24	2·62	83·49	2·02	7·61	6·82
10th month	80·92	0·90	11·81	2·53	79·44	2·11	9·48	8·97
				Postnatal Stages				
Birth to 5 days	79·60	0·90	13·09	2·35	72·68	1·65	17·48	8·19
6 to 15 days	80·06	0·80	14·18	1·80	71·42	1·94	17·98	8·66
16 to 30 days	79·58	0·82	15·30	1·58	73·61	1·71	17·45	7·23
31 to 60 days	81·65	0·78	13·73	1·38	73·94	1·57	18·00	6·49
61 to 120 days	80·14	0·83	15·27	1·32	73·64	1·72	17·60	7·04
121 to 515 days	77·24	1·15	17·56	1·63	65·20	5·48	19·99	9·33
Adult	75·42	1·16	19·51	1·46	60·59	8·27	19·89	11·25

* Inclusive of caecum, colon and rectum also.

** Inclusive of caecum and rectum also.

A consolidated picture about the developing intestines as a group, in case of buffalo, can be had from table 5 and figure 3 containing the relative statement in respect of its various segments.

From table 5 and fig. 3 it is seen that small intestine is the longest segment with maximum tissue weight and is followed by colon, rectum and caecum in succession. This order is maintained through both, the pre- and postantal stages. The relative length proportions between the small intestine and the colon, however, present an interesting feature.

During the 2nd month of intra-uterine life the ratio between small intestine to colon length works out to roughly about 2:1, which changes to about 6·5:1 during the 3rd month and to about 10:1 during the 4th month of foetal life, indicating thereby that the small intestine gains at a much faster rate than the colon during this period. The ratio then narrows down to about 7·5:1 to about 7:1 during the 5th and 6th months, when it increases back again to about 8:1 during the 7th through 9th month and then goes back again to about 7:1 at the close of the foetal term. After birth, small intestine to colon proportions narrow down to about 6:1 at about birth and down further to 4·5:1 at one year's of age as against in the neighbourhood of 4:1 in an adult.

On the basis of the relative length proportions of these two segments through the various stages of pre- and postnatal growth, one might conclude that while the small intestine gains and elaborates more during foetal life, the large intestine does so after the calf is born. While considering the tissue weight proportions of the two segments under reference, viz., the small intestine and the colon, it is seen that they represent almost a similar trend with relatively narrower ratios except during the 9th and 10th months of foetal life when they get wider.

At birth, however, the tissue weight proportions, return back to about 4:1 which gets further down to about 3·2:1 at one year of age as against 3:1 of the adult. It may, therefore, be interpreted to mean that the small intestine gains maximum tissue weight during the last quarter of foetal growth, a feature similar to that of abomasum indicated earlier. This is probably because after the calf is born abomasum and small intestine have to be more actively involved in supporting the early nutrition of calf than the other compartments of stomach or segments of intestine. The colon, on the other hand, seems to elaborate more after the calf is born and takes to roughage eating.

The dispositional shifts which the intestines make during the postnatal growth are quite interesting. They are chiefly situated in the left half of the abdominal cavity of the newly born calf. They then gradually move to the right epigastric zone due to the extension of the rumen on the left and also on to the right side ventrally.

Histologically (Fig. 4 and 5), the intestine also, like other compartments makes a simple beginning and have all the basic layers in their structure even during the early part of their development. The different segments have the usual layer of peritoneal covering except colon. It is because it develops in between the two layers of the mesentery supporting the small intestine.

The outermost coat is followed by the muscular coats of external longitudinal and inner circular muscle fibres, which in turn are followed by the submucosa and mucosa. Of these, submucosa and the lamina propria of mucosa contain a large number of free cells and the two remain indistinguishable from each other in the beginning for want of a defined muscularis mucosae, which develops later. The arrangements of muscularis and submucosa remains almost similar in all the segments of intestine except the first part where the submucosa develops duodenal glands (the Brunner's gland) and the lymphoid tissue in the lower part of the organ.

The mucosa of intestine on the other hand varies from segment to segment. It develops villi in the small intestinal portion and remains almost smooth in the rest. The intestinal villi, to start with, remain fewer but broader and change to numerous and narrower with the growth of foetus. The intestinal glands, however, develop throughout the length of intestine, which elaborate with foetal growth and come to have a good number of mucous cells distributed along their lining.

The Intestinal contents

A consolidated account of the distribution of wet ingesta in different segments of the intestine, as come across at different stages of postnatal growth in this study, will not be out of place and is summarised in table 6 and graphically represented in fig. 6.

TABLE 6

Showing the percentage of total wet-ingesta in different segments of intestine at different stages of postnatal growth in buffalo.

	Age in days						
	0—5	6—15	16—30	31—60	61—120	121—515	Over 5 Yrs
Total gut ingesta (gm.)	820·25	1067·54	1463·90	2805·20	6412·80	18908·40	84913·68
Total gut ingesta as per cent of body weight	2·88	3·55	4·17	6·42	10·79	15·07	17·57
Stomach (Details reported in Part I)	20·97	25·04	33·07	59·77	77·53	86·78	86·36
Small intestine	50·44	41·78	33·67	17·90	8·92	4·85	5·11
Caecum	0·85	0·96	1·01	1·23	1·43	1·19	1·02
Colon	13·41	15·83	17·90	11·48	7·50	4·50	3·80
Rectum	14·33	16·39	14·35	9·62	4·62	2·68	3·71
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00

It is seen from table 6 that while the total gut contents constantly increase with age (2·88% of body weight at about birth to 17·57% at maturity) both in absolute weight and weight in relation to body, their further apportionment to different sections of the gut reveals an interesting feature. During the early milk feeding regime the small intestine has the maximum contents and is followed by rectum, colon and caecum in succession. The stomach compartments as a whole, however, contain comparatively small amount of ingesta which gradually keeps on increasing with the passage of time.

The above sequence is maintained through the first 15 days of the calf. Thereafter the rectum and colon inter-change their relative positions. However, the two retain almost identical contents at the adult stage when small intestine, caecum, colon and rectum contain 5·11, 1·02, 3·80 and 3·71 per cent of ingesta respectively as against the stomach which accounts for 86·36 per cent.

THE ACCESSORY DIGESTIVE GLANDS

Of the accessory digestive glands only liver and pancreas have been followed for their development behaviour during the foetal life as under :

The Liver (Fig. 7).

Liver, the largest digestive gland, develops as an outgrowth of the primitive gut immediately posterior to the cardic end of the stomach as hepatic diverticulum, which makes its appearance even before the 30th day of embryonal life. It develops as an extensive glandular mass that extends ventrally and cranially and encloses the developing intestines alongwith the yolk stalk within its mass. Its growth is comparatively extensive during the early foetal life and the same gets retarded subsequently.

During the early foetal stages its contact with intestine is so intimate that the two are difficult to be separated. But during the later stages their intimate ties are unfastened and ultimately only the bile duct remains connecting them.

It is seen from table 7 that in about a 3-month old foetus liver accounts for about 154 per cent of digestive tract and 12 per cent of body by weight. While the absolute weight of liver increases continuously with march of time and growth of foetus, its relative proportion to both total digestive tract and body weight goes on decreasing and at about the 10th month of intra-uterine life it accounts for about 67·6 and 2·2 per cent of the total digestive tract and body respectively.

At birth its relative proportion to both, total digestive tract and body decrease further down to about 59 per cent of the gut and 2 per cent of the body weights. During the milk feeding regime and young age of calf it weighs proportionately heavier than that of adult and at the age of about a year it makes 30·55 per cent of total digestive tract and 1·90 per cent of body weight as against 20·79 per cent and 1·27 per cent in case of adult respectively.

The dispositional changes of liver during the postnatal growth are quite interesting. In newly born calf the liver lies between the stomach and diaphragm on either side of the median plane. It then gradually moves to the right of the median plane due to the extensive growth of rumen and reticulum on the left side. Detailed observations made on the measurements of developing liver are summarised in table 7 and their averages have also been graphically represented in fig. 8.

The Pancreas

This digestive gland gets evident during the 3rd month of foetal life and is seen as a diffused structure in between the developing duodenal loop of the small intestine and accounts for about 1·42 and 0·11 per cent of total gut and body by weight respectively. It then increases in proportion to both total digestive tract and body upto the mid term and shows a decline during the 8th and 9th month, increasing again in the 10th month of foetal growth as can be seen from table 6 and Fig. 8.

TABLE 7

Showing the liver and pancreatic measurements at different stages of pre- and postnatal growth in buffalo.

	Liver tissue weight measurements			Pancreas tissue weight measurements		
	Average (gm)	% of total digestive tract	% of empty body weight	Average (gm)	% of total digestive tract	% of empty body weight
			Prenatal Stages			
3rd month	2·17	153·90	11·74	0·02	1·42	0·11
4th month	9·21	149·51	10·34	0·21	3·41	0·24
5th month	29·66	122·61	10·83	0·85	3 51	0·31
6th month	67·38	113·64	5·72	4·29	7·24	0·36
7th month	107·91	95·17	4·65	6·21	5·48	0·27
8th month	148·75	83·39	3·07	8·90	4·99	0·18
9th month	246·20	79·16	3·04	12·02	3·87	0·15
10th month	356·25	67·62	2·23	31·47	5·97	0·20
			Postnatal Stages			
Birth to 5 days	579·50	58·84	2·10	42·87	4·35	0·16
6 to 15 days	587·40	52·17	2·02	43·60	3·87	0·15
16 to 30 days	638·00	41·35	1·90	47·80	3·09	0·14
31 to 60 days	771·00	34·02	1·89	55·20	2·44	0·13
61 to 120 days	1060·00	31·00	2·00	71·40	2·09	0·13
121 to 515 days	2032·00	30·55	1·90	123·00	1·85	0·12
Adult	5043·60	20·79	1·27	269·56	1·11	0·07

At birth the relative proportions are found to be 4·35 and 0·16 per cent of total digestive tract and body respectively. It then shows a proportionate decline althrough down to the adulthood both in relation to total digestive tract and body. At the age of about a year it weighs 1·85 per cent and 0·12 per cent respectively as against the respective figures of 1·11 per cent and 0·07 per cent of the adult. It may, however, be noted that like liver, pancreas also has proportionately heavier weights during the milk feeding regime of calf than the adult.

SUMMARY AND CONCLUSIONS

Developmental studies based on 150 foetuses and 35 calves of buffalo indicate that the intestine has a humble beginning. The relative proportions of small intestine to colon length vary from 2:1 during second month of intra-uterine life through 10:1 during 4th month of foetal life, 6:1 at birth to 4 : 1 in adult ,indicating thereby that the small intestine elaborates more during foetal life, as against the large one which does so after the calf is born. The dispositional shifts, which the intestines make during the postnatal growth are quite interesting. In newly born calf they are primarily situated in the left half of the abdominal cavity from where they move to the epigastric zone on the right side due to the extensive growth of the rumen on the left.

Histologically also the intestines have a simple start but have all the basic layers in their structure even during the early part of foetal development except the colon which lacks a peritoneal covering because of its development between the mesenteric layers supporting the small intestine. As in other organs, the lamina propria and the submucosa of intestine also remain merging and indistinguishable from each other for want of a defined muscularis mucosae in the beginning, which develops later. The submucosa develops Brunner's glands in the region of duodenum also.

The mucosa which remains almost similar in the different segments of intestine to start with gets differentiated as villiated in small intestine, smooth in caecum and colon and ridged in case of colon and rectum. They, however, develop intestinal glands in common with the growth of foetus.

The distribution of ingesta in the different segments of intestine through postnatal stages presents an interesting feature. During early milk feeding regime the small intestine has the maximum contents and is followed by rectum and colon and the caecum contains only nominal amounts. As the calf grows the colon and rectum inter-change their positions.

Of the liver and pancreas liver shows an extensive out growth even before the 40th day of embryonal life. As it grows it encloses the developing intestines within its mass alongwith yolk stock. Its growth remains comparatively extensive during the early foetal life which gets retarded subsequently. Its close and intimate connections with the intestine gradually get unfastened leaving the bile duct as the only remnant of this tie.

The dispositional changes of liver during the postnatal growth are again interesting. In a newly born calf it occupies a median position between the stomach and diaphragm and then gradually moves to the right due to the extensive growth of raticulo-rumen on the left side.

Pancreas on the other hand originates as diffused structure developing in between the duodenal loop which subsequently grows and elaborates with the passage of time and growth of foetus. It weighs proportionately heavier during the milk feeding regime than that of the adult stage.

Note—This part is followed by Part III—Structure of the Fore-gut in buffalo—*Bos bubalis* L.

Fig. 1: Showing the Developing Intestines in situ during early foetal stage in buffalo.

Fig. 1.1: A 50-day stage showing the developing intestines alongwith yolk stalk and extensive liver mass that fills the abdominal cavity almost completely. The developing heart and the lungs are also seen in the thoracic cavity.

Fig. 1.2: A 60-day stage showing the progressive development of intestines.

Fig. 2: Showing the Development of Intestine during foetal growth (41–310 days) in buffalo. (Size in relation to mm. scale alongside them).

Fig. 2.1: A 41-day stage
Fig. 2.2: A 43-day stage
Fig. 2.3: A 45-day stage
Fig. 2.4: A 50-day stage
Fig. 2.5: A 60-day stage
Fig. 2.6: A 65-day stage
Note the progressive development of the intestine coils along the yolk stalk (Ys) during these stages.

Fig. 2.7: A 70-day stage
Fig. 2.8: A 75-day stage
Fig. 2.9: A 80-day stage
Fig. 2.10: A 85-day stage
Fig. 2.11: A 90-day stage
Fig. 2.12: A 100-day stage
Note the tightly coiled nature of the intestinal loops.

Fig. 2.13: A 110-day stage
Fig. 2.14: A 120-day stage
Fig. 2.15: A 130-day stage
Fig. 2.16: A 140-day stage
Fig. 2.17: A 150-day stage
Fig. 2.18: A 175-day stage
Note the fast elaborating coils of the small intestine.

Fig. 2.19: A 200-day stage
Fig. 2.20: A 225-day stage
Fig. 2.21: A 250-day stage
Fig. 2.22: A 275-day stage
Fig. 2.23: A 300-day stage
Fig. 2.24: A 310-day stage
Note the fast elaborating small intestine during the last phases of intra-uterine life and the developing caecum. Accumulation of muconeum at the close of the gestational life is note worthy.

Fig. 4: Showing the Histological Development of small Intestine in Buffalo.

Fig. 4.1: T.S. through small intestine of a 50-day foetus. Note the developing muscularis and the mucosal villi.

Fig. 4.2: T.S. through small intestine of a 60-day foetus. Note the developing muscularis and villi.

Fig. 4.3: T.S. through small intestine of a 75-day foetus. Note the profusely developing villi.

Fig. 4.4: The same as figure 4.1 magnified to show columnar cells of a developing villus with prominent nuclei.

Fig. 4.5: T.S. through small intestine of a 100-day foetus. Note the elaborating muscularis and the mucosal villi.

Fig. 4.6: T.S. through small intestine of a full term foetus passing through a Peyer's patch-marked as B.

Fig. 4.7: Portion 'A' of figure 4.6, magnified to show the fully developed muscularis, submucosa and muscularis mucosae of the mucosa.

Fig. 4.8: Portion 'B' of figure 4.6, magnified to show the lymphoid nature of the Peyer's patch.

Fig. 5: Showing the Histological Development of Large Intestine in buffalo.

Fig. 5.1: L.S. through caecum of a full term foetus. Note the disposition of muscularis and mucosa.

Fig. 5.2: The same as figure 5.1. Portion marked 'A' magnified to show the caecal glands.

Fig. 5.3: T.S. through colon of a full-term foetus.

Fig. 5.4: A portion of figure 5.3 magnified to show the glands of the colon mucosa.

Fig. 5.5: T.S. through rectal wall of a full-term foetus. Note the extensive development of the longitudinal and circular muscles.

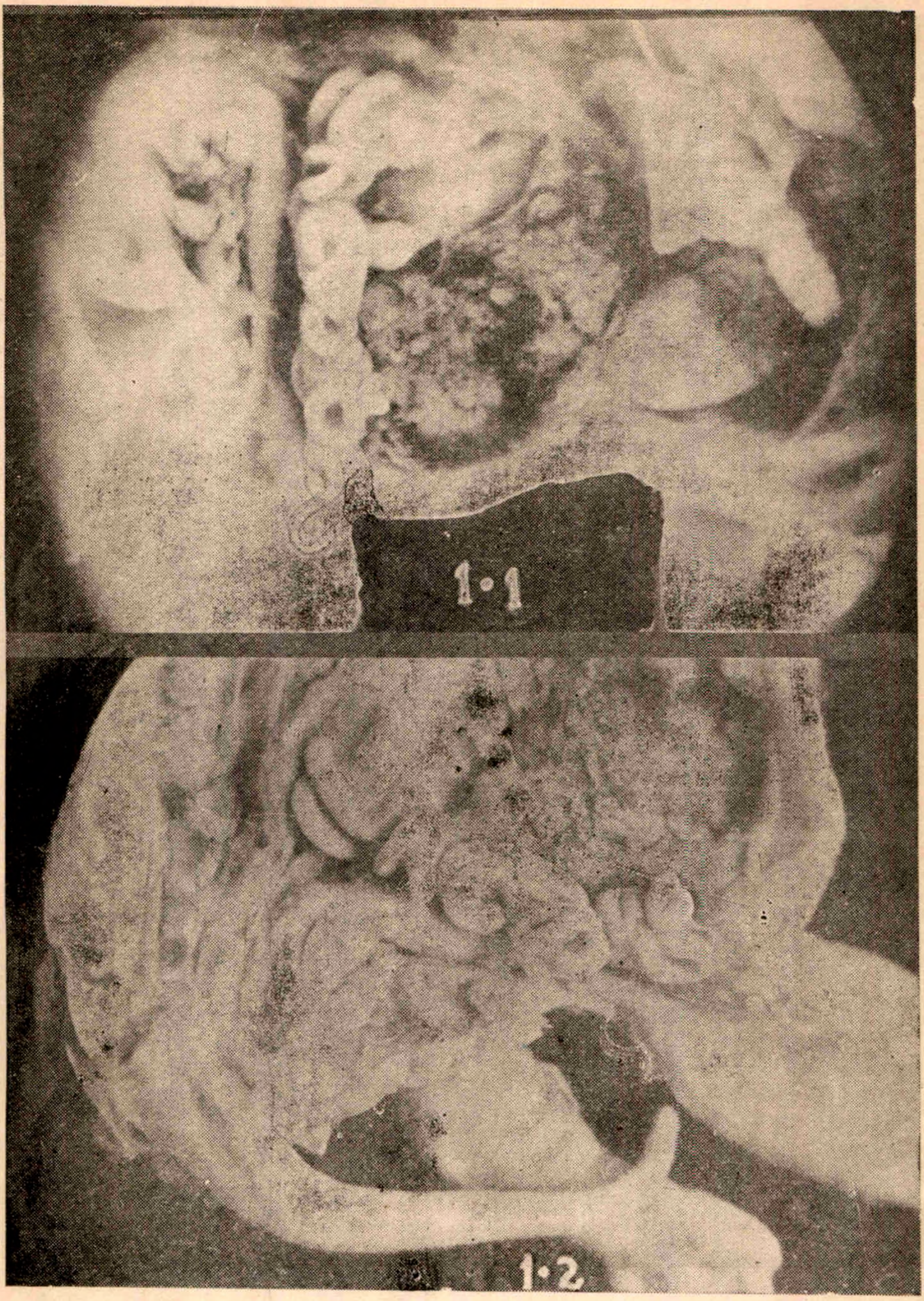
Fig. 5.6: T.S. through the rectal mucosa of a full-term foetus magnified to show the rectal glands containing lot of goblet cells.

Fig. 7: Showing the Development of liver in buffalo. (Size in relation to mm. scale alongside them).

Fig. 7.1: A 77–day stage
Fig. 7.2: A 87–day stage
Fig. 7.3: A 89–day stage
Fig. 7.4: A 94–day stage
Fig. 7.5: A 105–day stage
Fig: 7.6: A 110–day stage
Fig. 7.7: A 120–day stage
Fig. 7.8: A 130–day stage
Fig. 7.9: A 140–day stage
Fig. 7.10: A 150–day stage
Fig. 7.11: A 175–day stage
Fig. 7.12: A 200–day stage

The extensive nature of the liver during the earlier stages of foetal growth is worth noting.

Fig. 7.13: A–day old calf stage. Note the location of liver on either side of the median plane.



Fig, 1. Showing the Developing Intestines in situ during Early Foetal stages in Buffalo.

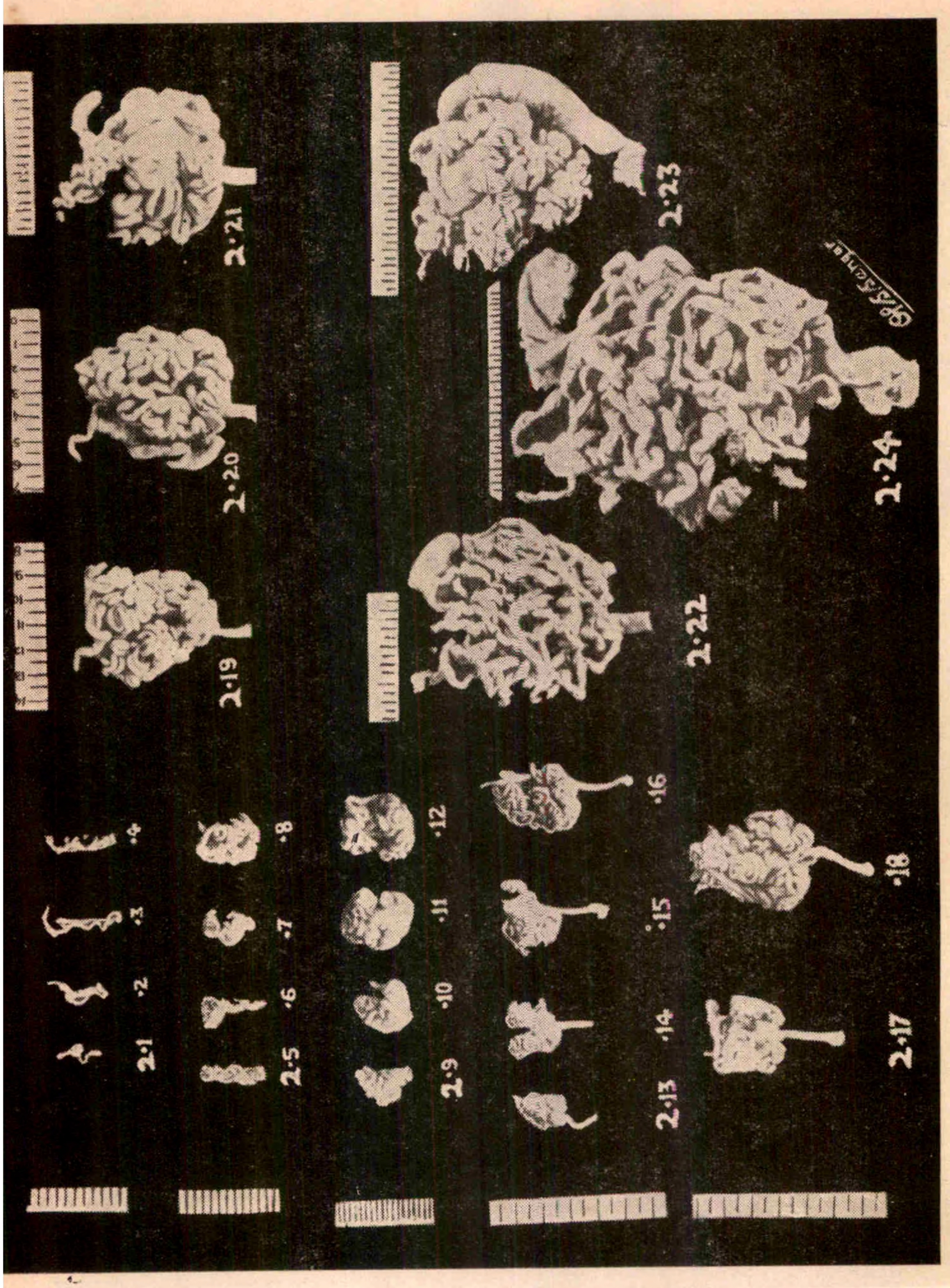
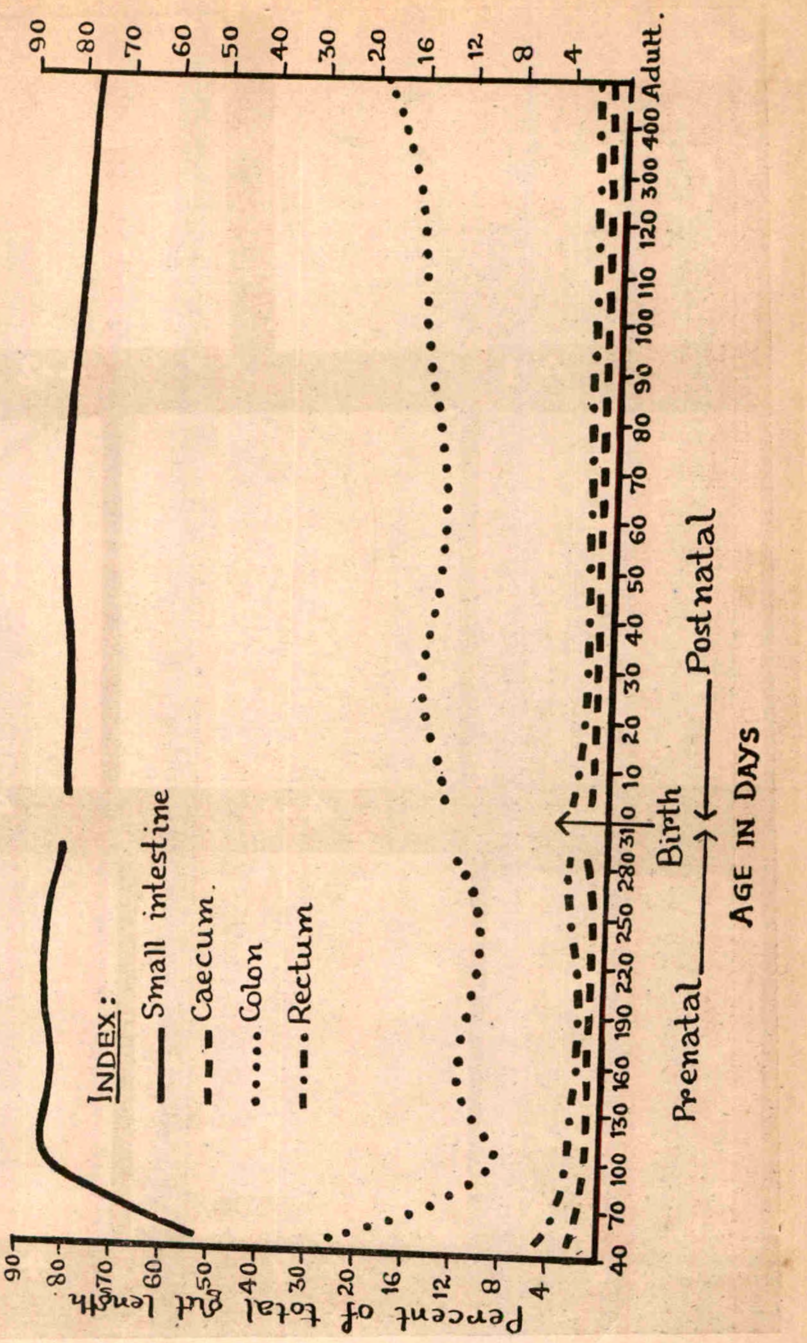


Fig. 2. Showing the Development of Intestine during Foetal Growth (41–310 days) in Buffalo. (Size in relation to mm. scale alongside them).

Fig. **3**: Showing the relative length of different intestinal segments during pre- and postnatal growth in buffalo.



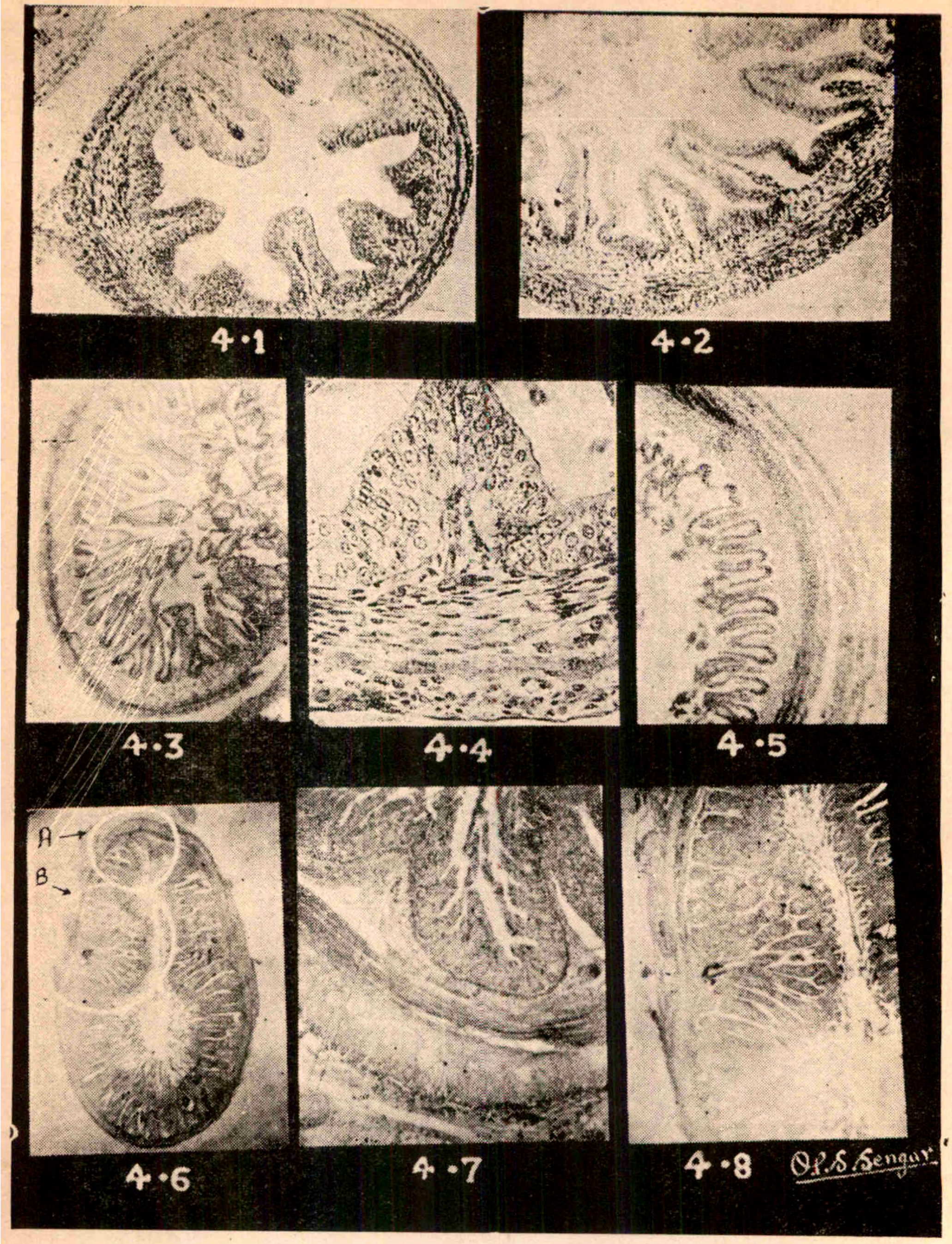


Fig. 4. Showing the Histological Development of Small Intestine in Buffalo.

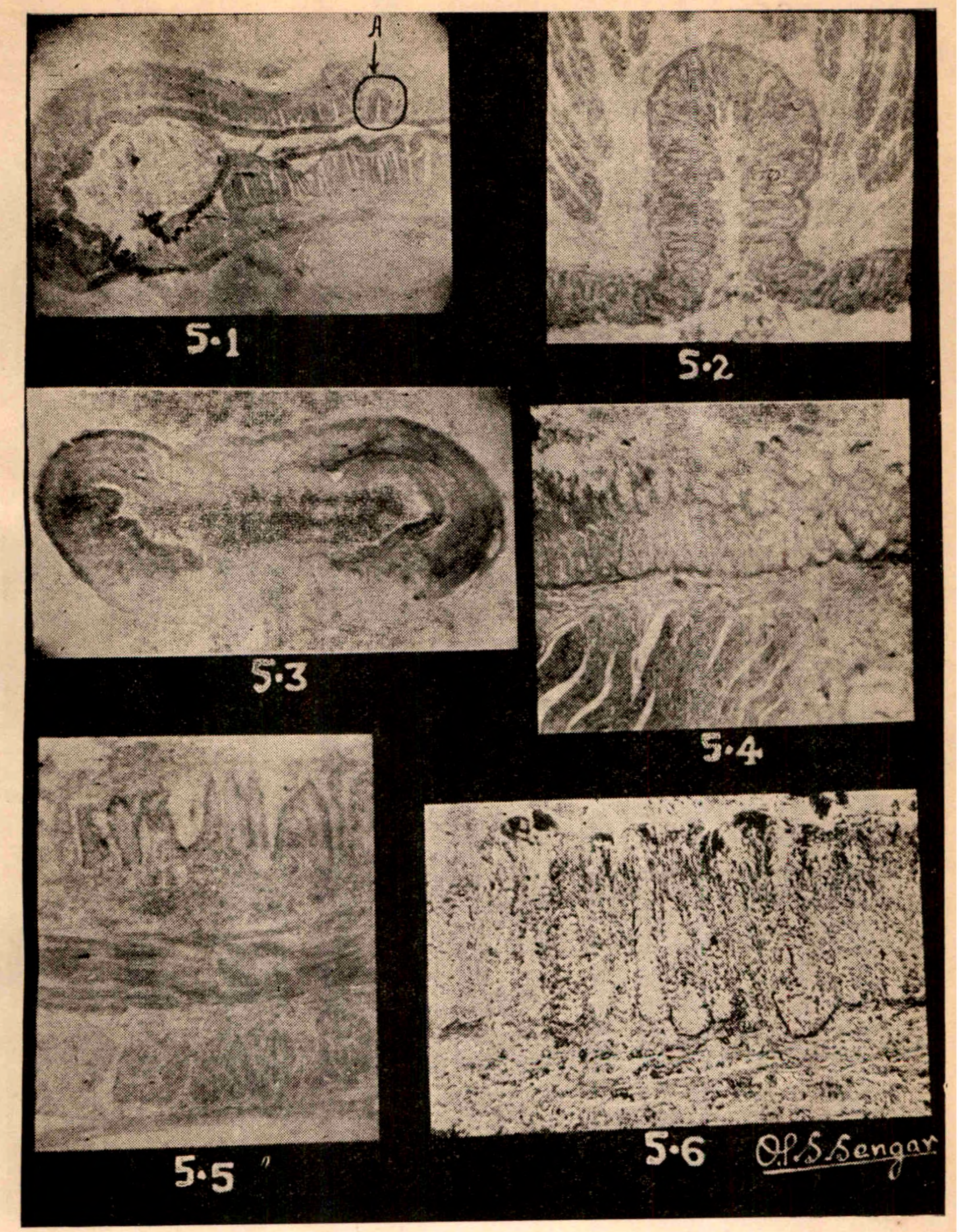


Fig. 5. Showing the Histological Development of Large Intestine in Buffalo.

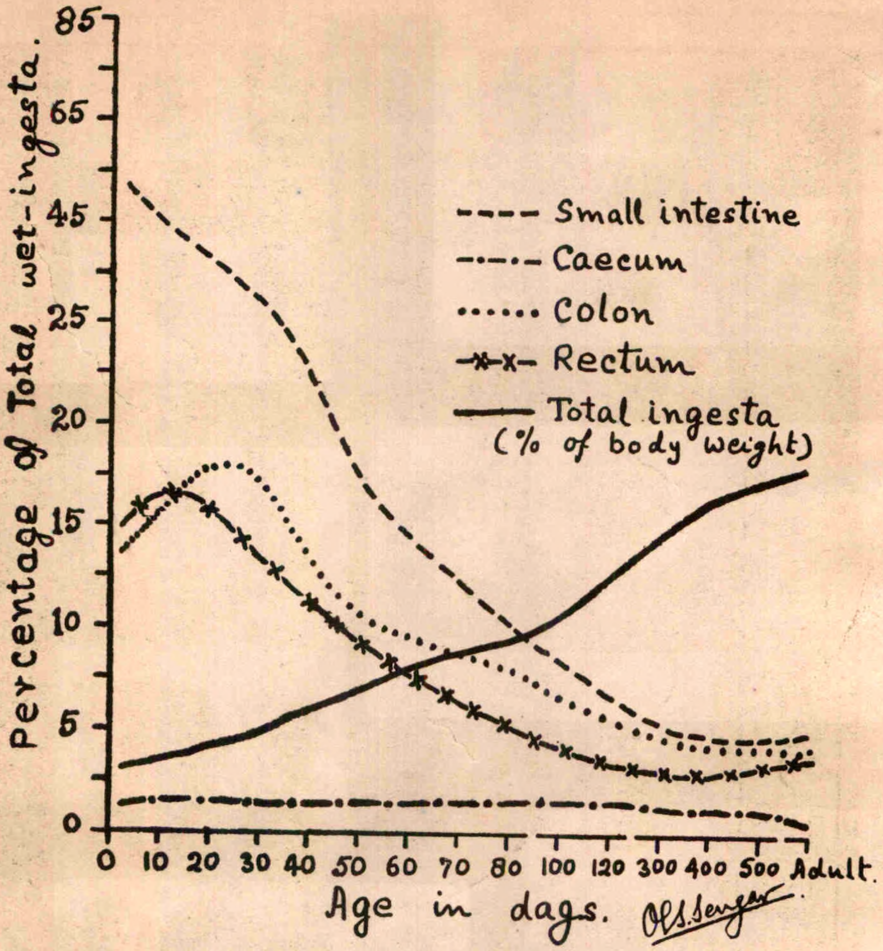


Fig. 6. Showing the Percentage of total Wet-Ingesta in different Segments of the Intestine at different Stages of Postnatal Growth in Buffalo.

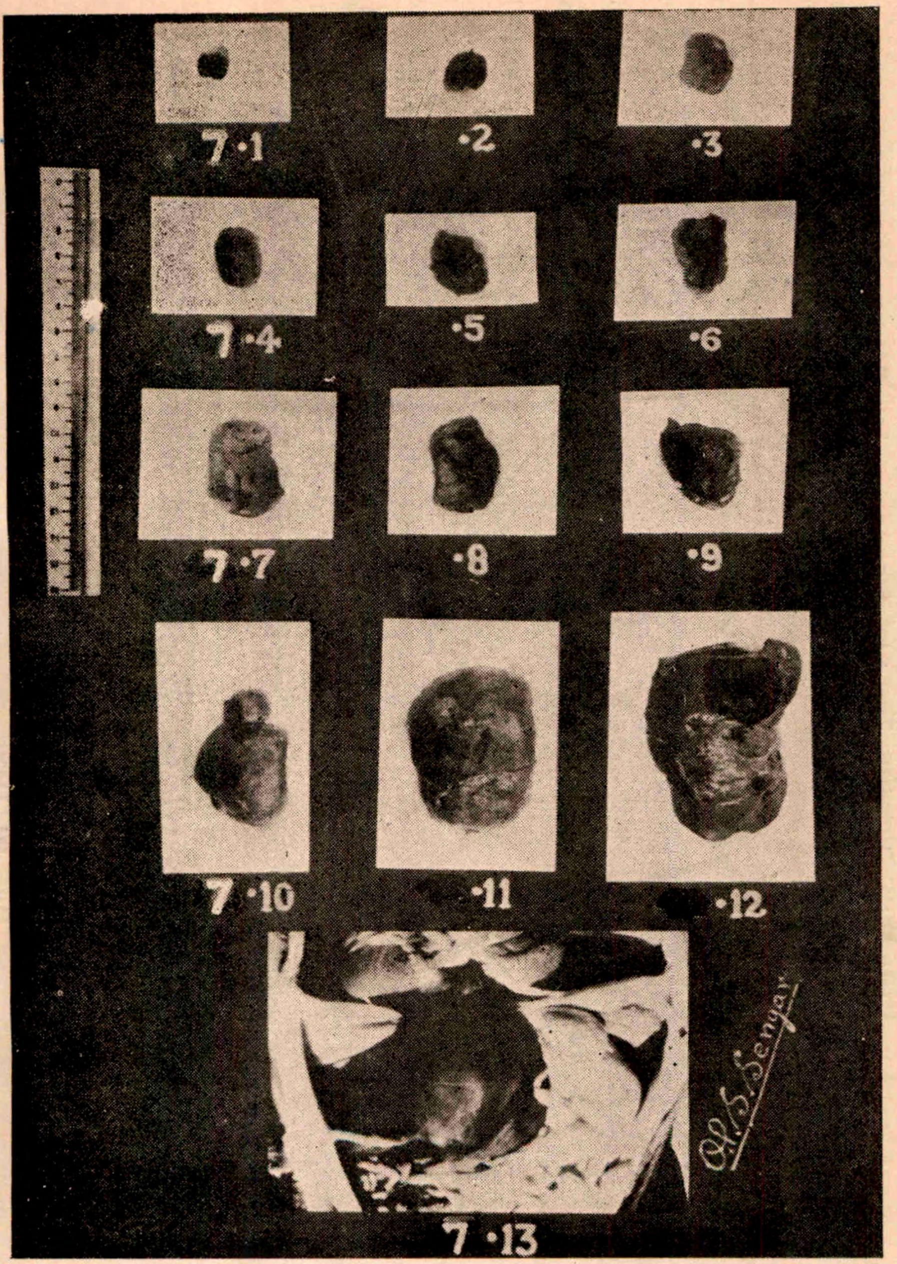
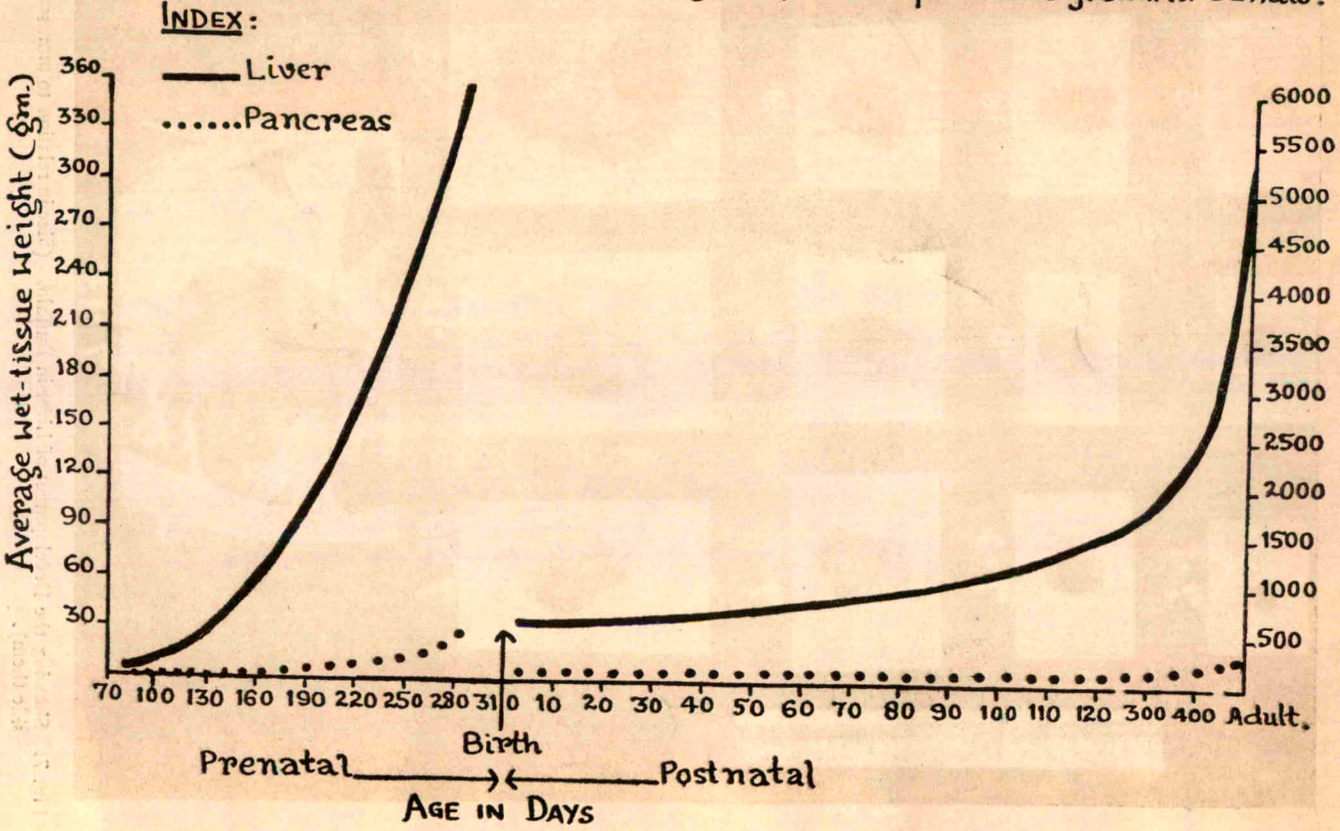


Fig. 7. Showing the Development of Liver in Buffalo. (Size in relation to mm. scale alongside them).

Fig. 8: Showing the wet-tissue weight of liver and pancreas at different stages of pre- and postnatal growth in buffalo.



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THE AMINO-ACID COMPOSITION OF BRUCELLA SPECIES

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The differentiation of bacterial species according to their amino-aci and peptide content as revealed by paper chromatography has been attempte for the genera *Lactobacillus* and *Micrococci* by several workers[1-6]. Mehra *et a* (1960)[7] reported the amino-acid composition of Trichomonad protozoa b column chromatography. Such literature on Brucella species, however, coul not be available. It was, therefore, of interest to study the amino-acid compo sition of the main Brucella species viz. *Br. abortus*, *Br. melitensis* and *Br. su* by two dimensional paper chromatography.

MATERIALS AND METHODS

The cultures of Brucella used in this study were *Br. abortus* strain 54 *Br. abortus* strain 99, *Br. Suis* strain 1330 and *Br. melitensis* strain 16 M.

Paper chromatography for amino-acid assay of the hydrolysed bacteria cells and HSWS (Pathak and Singh, 1967)[8] was conducted according to th technique of two dimensional paper chromatography described by Block (1958) Solvents used were Butanol: Acetic acid: Water (120: 30: 150) and Phenol Water: Ammonia (100:10:0·5).

RESULTS AND DISCUSSION

The individual amino-acids detected in the acid hydrolysate of the frac tion HSWS and in those of various other species of *Brucella* by two dimension paper chromatography are shown in table 1.

Br. abortus-99 and *Br. abortus*-544 were found to contain the same 1 amino-acids. Besides there were 2 unidentified spots which were also detecte in HSWS. There were some differences in the amino-acid contents of the othe two species (*Br. melitensis* and *Br. suis*) fig. 1-4 but it is difficult to conclud from these results that this technique would provide a basis for an authenti classification of the genus. Physiological age and composition of the growt medium are known to affect the amino-acid content of bacteria (Gregory an Mabbitt, 1957). The importance of standardizing the composition of th medium, therefore, has also been emphasized by them (loc. cit.).

Further work on more accurate quantitative measurements by colum chromatography is needed before usefulness of this technique as an adjunct t existing methods of bacterial identification and classification can be assessed.

TABLE I

Amino-acid Content of Brucella Species

Amino-acids	*HSWS*	*Br. abortus* 99	*Br. abortus* 544	*Br. melitensis* 16M	*Br. Suis* 1330
Cystine	—	+	+	—	—
Aspartic acid	+	+	+	+	+
Glutamic acid	+	+	+	+	+
Serine	+	+	+	+	+
Glycine	+	+	+	+	+
Threonine	—	+	+	+	+
Alanine	+	+	+	+	—
Tyrosine	—	+	+	+	+
Methionine	—	+	+	+	+
Valine	—	+	+	+	+
Phenyl-alanine	—	+	+	+	+
Isoleucine	+	+	+	+	+
Leucine	+	+	+	+	+
Proline	—	+	+	—	—
Unidentified spots	2	2	2	2	1

SUMMARY

The amino-acid composition of the three *Brucella* species viz. abortus, melitensis and suis, as revealed by paper chromatography of their respective hydrolyzed material is reported.

ACKNOWLEDGEMENT

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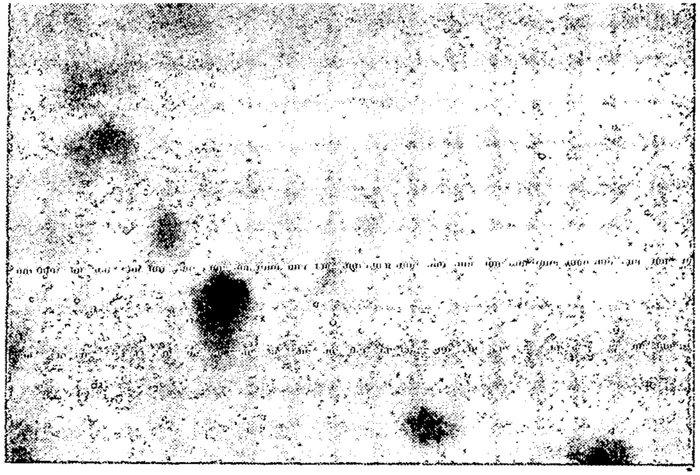

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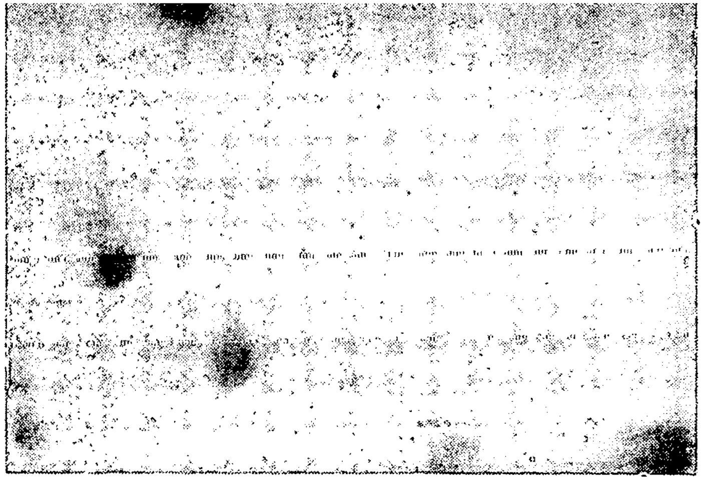

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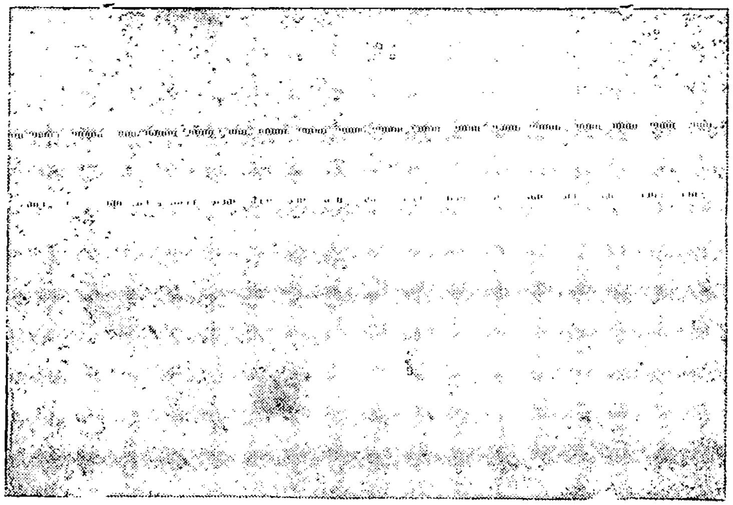
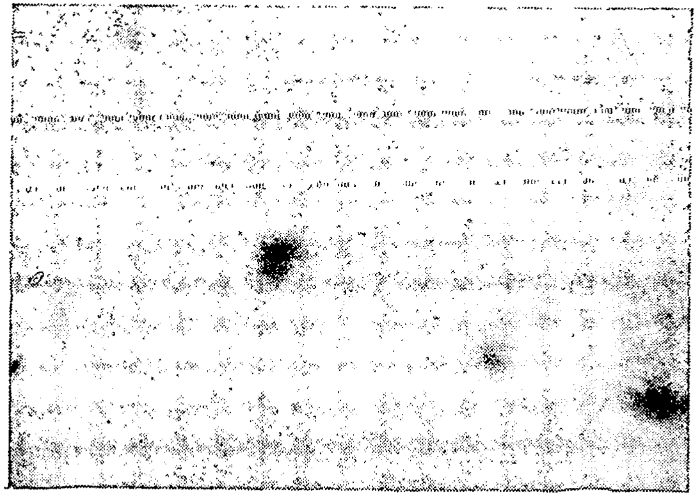


Br. Melitensis 16M



Br. suis 1330

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INHERITANCE OF RUST RESISTANCE IN SOME EXOTIC VARIETIES OF LINSEED

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It has been estimated that nearly 23 per cent of the world crop produce is destroyed by pests and diseases and the production may be pushed up by about 10 per cent if the suitable measures to control the diseases could be adopted (Vasudeva, 1962). Of all the diseases of linseed in India, the rust disease, *Melampsora lini* (Pers.) Lev.is, perhaps, the most important from the point of view of damage it causes to the crop. Since the pattern of inheritance of any character is likely to vary with parental combinations involved, it is necessary to study the nature of inheritance in different combinations. During the present study inheritance of rust resistance has been studied in some of the newly introduced varieties of linseed.

REVIEW OF LITERATURE

Flor (1946, 1947, 1955 and 1956) has shown that rust resistance or susceptibility is conditioned by an interrelationship between the genetic factors present in the parasite and the host. Myers (1937) found immunity from the rust to be conditioned by duplicate factors L and M. Deshpande and Jeswani (1951) obtained 3:1 ratio of resistant to susceptible lines and found no linkage with seed and flower characters. Henry (1950) and Chu and Culbertson (1952) also found 3:1 ratio of resistant to susceptible segregates, but in some cases Henry also observed a ratio of 15:1. The mode of inheritance of rust resistance with regard to different sources of resistance have been reported by various workers from Indian Agricultural Research Institute, New Delhi, which include Deshpande and Jeswani (1951), Jeswani *et al.* (1963) and Jeswani and Guglani (1964).

MATERIAL AND MATHOD

Eleven commercial linseed varieties have been included in the present study. Of these, 8 bearing U.S.D.A. accession numbers were collected from United States by Dr. R. P. Singh, Scientist, National Botanic Gardens, Lucknow. Three indigenous varieties were collected by Dr. D. K. Dubey, Asstt. Prof. of Botany, R.B.S. College, Agra. All the three varieties of indigenous stock were susceptible to rust. To get the nature of rust resistance in exotic varieties nine intervarietal crosses between 8 exotic 3 susceptible indigenous varieties were made. Progeny of the crosses were checked for susceptibility in F_1,F_2 and backcross progenies.

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OBSERVATIONS AND RESULTS

The F_1 hybrids of 5 crosses, with the exception of the crosses between C.I.1483, C.I.795 and C.I.763 were completely rust resistant and thus exhibited the dominance of rust resistance over susceptibility. C.I. 795 and C.I. 763 exhibited susceptibility in field conditions and accordingly their hybrids were also susceptible. The remaining two hybrids involving C. I. 1483, which itself is resistant were found to contain mild infection of rust. The nature of resistance in these hybrids was considered to be of partial dominance. The data on various F_2 and test-crosses have been arranged in table 1.

TABLE 1

The segregating behaviour of F_2 and test-cross generations of 9 intervarietal hybrids and mode of inheritance to rust reaction.

Sl. No.	Cross	Generation	Number of plants		Ratio
			Resistant	Susceptible	R : S
1.	C. I. 795×S.36	F_2	...	242	All S
	,,	Test	...	21	,,
2.	C. I. 763×S.36	F_2	...	192	,,
	,,	Test	...	19	,,
3.	C. I. 1483×Laharpur	F_2	36	146	1 : 3
	,,	Test	...	23	All S
4.	C. I. 1483×S.36	F_2	34	126	1 : 3
	,,	Test	...	31	All S
5.	C. I. 378×S.36	F_2	83	18	3 : 1
	,,	Test	17	13	1 : 1
6.	C. I. 693×Laharpur	F_2	166	41	3 : 1
	,,	Test	10	10	1 : 1
7.	C. I. 1149×M.10	F_2	88	19	3 : 1
	,,	Test	16	13	1 : 1
8.	C. I. 388×Laharpur	F_2	198	61	3 : 1
	,,	Test	16	12	1 : 1
9.	C. I. 470×S.36	F_2	120	16	15 : 1
	,,	Test	28	10	3 : 1

A perusal of the table shows that the hybrids at serial number 1 and 2 had all susceptible plants both in F_2 and test-cross progenies. The hybrids numbered 3 and 4 showed more susceptible than resistant plants and their F_2 ratio showed a good fit in 1 resistant (R): 3 susceptible (S) types, while test-cross progeny resulted in all susceptible plants. All the remaining hybrids, except for the last, segregated into 1 R (resistant) : 1 S (susceptible) in the test crosses and 3 R: 1 S in F_2 progenies. The last hybrid C.I.470 × S.36, showed 3R: 1 S segregation in test-cross progeny and 15R: 1S in F_2, indicating the possibility of involvement of duplicate genes in this case.

DISCUSSION

The hybrids of five varieties have shown that the resistance to rust is dominant over susceptibility. This is in agreement with the findings of early workers (Henry, 1930; Myers, 1937; Flor, 1946; 1947; Deshpande and Jeswani, 1951; Jeswani *el al.*, 1963 and Jeswani and Guglani, 1964).

The F_2 segregation of four hybrids, irrespective of susceptible Indian parents, shows that rust reaction is controlled by a single pair of genes. Similar monogenic mode of inheritance was obtained for a number of linseed varieties by Deshpande and Jeswani (1951), Jeswani *et al.* (1963) and Jeswani and Guglani (1964).

A segregating ratio of 15R: 1S was obtained in the cross involving C.I. 470, showing that two dominant genes are responsible for resistance and they act in duplicate mode. Earlier observations of Henry (1930) and Myers (1937) also show that resistance to rust is controlled by a pair of duplicate genes. Jeswani *et al.* (1963) and Jeswani and Guglani (1964) also reported the involvement of two genes in duplicate fashion in a number of varietal crosses.

The behaviour of hybrids involving C.I. 1483 may be explained on the basis of incomplete dominance of resistance to susceptibility, with the result F_1 hybrids exhibited slight infection of rust. In F_2 generation, these hybrids showed segregation and a ratio of 3S: 1R. The absence of completely resistant plant in test-cross progeny was on the expected lines.

It appears from the foregoing account based on the behaviour of hybrids involving C.I. 1483, that this variety has some weaker gene for rust resistance, which is not completely dominant over susceptibility. As a result of this weaker gene, F_1 plants were susceptible and F_2 plants were expected to segregate in 1:2:1 ratio. But 1R:3S segregation in the present study is due to the union of last two groups into one. The presence of all susceptible plants in test cross progeny was also expected. Thus, in this variety the gene for resistance is incompletely dominant over susceptibility. Flor (1956) has previously reported the incomplete dominance of resistance in some cultivars of linseed. Myers (1937) has also noted the similar situations and postulated the allelic genes L^r and M^r which were recessive to L and M but partially dominant over l and m.

SUMMARY

Eight varieties of the exotic stock were tested for rust reaction, which showed varied behaviour in F_1, F_2 and test-cross progenies. Two varieties viz., C. I. 763 and C. I. 795, which were themselves susceptible, showed all susceptible plants in the three progenies. C. I. 1483 showed partially resistant F_1 plants and F_2 ratio of susceptible to immune plants was 3:1. The F_1 hybrids of five varieties were resistant and the F_2 ratio of immune to susceptible segregates in case of four varieties was 3:1 and in case of C.I. 470 was 15:1. On the basis of segregating progeny it has been concluded that C.I. 763 and C.I. 795 do not contain genes which cause immunity. C.I. 1483 possesses a gene which is incompletely dominant over the gene causing susceptibility. In four varieties resistance is controlled by only one dominant gene while in C.I. 470 by two dominant genes which act in duplicate mode.

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EFFECT OF TEMPERATURE ON THE COAGULATION CONSTANTS OF FERRIC TELLURATE, CHROMIUM TELLURATE, CERIC OXIDE AND VANADIUM PENTAOXIDE SOLS

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SUMMARY

The coagulation of ferric tellurate, chromium tellurate, ceric oxide and vanadium pentaoxide sols has been studied in the presence of electrolytes at different temperatures by viscometric technique. The values of the constants a, m and n of Bhattacharya's equation[1] have been evaluated at different temperatures during the coagulation of the sols in the presence of electrolytes. The increase in temperature has been found to cause a marked decrease in the value of each constant. The decrease in the value of $(a+m)$ shows that the stability of the sols decreases as the temperature increases.

INTRODUCTION

It has been observed that rise of temperature often hastens the coagulation of colloids. Lachs and Goldberg[2] have studied the coagulation at different temperatures and obtained a straight line by plotting the time t_s of coagulation against the ratio η/T, where η is the viscosity of the medium and T is absolute temperature. The influence of temperature on the slow coagulation of copper oxide sols has been studied by Freundlich and Basu[3] who have obtained straight line by plotting t_s against η/T.

In previous publications[4-7] we nave studied the effect of dilution, dialysis, non-electrolytes and ageing on the constants a, m, n, of Bhattacharya's equation $C = a + \frac{m.1/t}{n+1/t}$. The theoretical justification of this equation has been put forward by Ghosh and Gangopadhyay.[8] In their derivation they have treated temperature as a constant factor, but if temperature is allowed to vary, the constants 'a', 'm' and 'n' obviously will no longer have the same value at all temperatures, as these constants are related to temperature either directly or indirectly.

Recently, the effect of temperature on the coagulation of sols is engaging fresh attention. Kharin and Chaikovskaya[9] have studied theoretically the effect of temperature on sulphur sol.

In this paper an attempt has been made to study the effect of temperature on the constants a, m and n for some lyophobic sols—ferric tellurate, chromium tellurate, ceric oxide and vanadium pentaoxide.

EXPERIMENTAL

Ferric tellurate and chromium tellurate sols were prepared by the method reported earlier[10] and were dialysed.

Ceric oxide sol was prepared by the method of Blitz.[11] A 5% solution of pure ceric ammonium nitrate was allowed to stand for a week in a pyrex flask when it became turbid and the colour changed from the original reddish orange to more or less greenish yellow. The sol was obtained which was then dialysed for about a month.

Vanadium pentaoxide sol was prepared by treating about 15*g*. of ammonium vanadate in 15 ml conc. HNO_3 in a porcelain basin with constant stirring. The precipitate so formed was then filtered off and well washed with water till the dark red sludge began to give red colour in the filtrate. The precipitate was then transferred to a conical flask and was shaken in a litre of water to convert it into a dark red coloured sol which was subjected to dialysis.

Viscosity measurements were made by Scarpa's method[12] modified by Farrow[13] and improved by Prasad and co-workers.[14] The temperature was controlled using a Gallenkamp thermostat. The progress of coagulation was detected by recording changes in viscosity. For each set of observations 5 ml of electrolyte of known concentration was added to 5 ml of sol and the viscosity was measured at different intervals. Several sets of observations were taken with different concentrations of coagulating electrolyte, but the concentrations of the electrolyte were so adjusted as to cause only slow coagulation. The whole process was repeated at different temperatures. The relative change of viscosity was determined by the ratio $\frac{\eta-\eta_0}{\eta_0}$, where η_0 is the initial viscosity and η is the viscosity at the end of the interval time 't'. This ratio was taken according to Freundlich[15] and Gann[16] as a measure of relative increase in coagulation (x).

The point of inflexion in curves (Fig. 1) obtained by plotting $\frac{\eta-\eta_0}{\eta_0}$, (i.e., degree of coagulation, x) against time were taken to denote same stage of coagulation $\left(\frac{d^2x}{dt^2}=0\right)$ brought about by adding different concentrations of the electrolyte. The reciprocal of the different times (1/t) corresponding to the points of inflexion[17] were plotted against the respective concentrations (C) (Fig. 2). The intercept obtained on the concentration axis gives the value of constant 'a' when $1/t \to 0$. Knowing the value of 'a', 1/(C-a) was plotted against 't', (Fig. 3) and the curve was found to be linear. The intercept on 1/(C-a) axis gives 1/m and the tangent on 't' axis gives n/m, from these 'm' and 'n' were evaluated. The Figs. 1, 2 and 3 have been given for the coagulation of ferric tellurate sols by KCl at 20°C. Similar curves were obtained for other sols at different temperatures and with differe electrolytes.

OBSERVATIONS

TABLE 1

Values of the constants a, m and n at different temperatures.

Sol.	Electrolyte	Temp. °C	a mM/l	m mM/l	a+m (mM/l)	n (min.)
Ferric tellurate	KCl	20	160·0	153·85	313·85	0·046
		30	140·0	111·11	251·11	0·025
		40	110·0	100·00	210·00	0·013
		50	70·0	87·00	157·00	0·007
	K_2SO_4	20	1·00	1·43	2·43	0·053
		30	0·80	1·33	2·13	0·040
		40	0·60	1·17	1·77	0·027
		50	0·40	1·17	1·57	0·018
	$K_3Fe(CN)_6$	20	0·50	1·25	1·75	0·075
		30	0·40	0·87	1·27	0·053
		40	0·25	0·77	1·02	0·034
		50	0·20	0·62	0·82	0·021
Chromium tellurate	KCl	20	240·0	250·00	490·00	0·030
		30	220·0	185·18	405·18	0·015
		40	200·0	156·25	356·25	0·009
		50	190·0	143·00	333·00	0·006
	K_2SO_4	20	0·90	5·00	5·90	0·200
		30	0·80	2·50	3·30	0·087
		40	0·50	2·08	2·58	0·064
		50	0·40	1·40	1·80	0·044
	$K_3Fe(CN)_6$	20	0·50	1·81	2·31	0·071
		30	0·40	1·00	1·40	0·030
		40	0·30	0·87	1·17	0·023
		50	0·10	0·80	0·90	0·018
Ceric oxide	KCl	25	10·0	6·25	16·25	0·036
		35	9·0	6·10	15·10	0·025
		45	8·0	5·68	13·68	0·017

TABLE 1 (*Contd.*)

Values of the constants a, m and n at different temperatures.

Sol.	Electroyte	Temp. °C	a mM/l	m mM/l	a+m mM/l	n $(\text{min.})^{-1}$
Ceric oxide	K_2SO_4	25	0·60	0·666	1·266	0·0720
		35	0·50	0·526	1·026	0·0326
		45	0·40	0·500	0·900	0·0250
	$K_3Fe(CN)_6$	25	0·15	0·526	0·676	0·0358
		35	0·10	0·435	0·535	0·0234
		45	0·05	0·345	0·395	0·0144
Vanadium pentaoxide	KCl	25	2·50	8·70	11·20	0·0500
		35	2·00	6·25	8·25	0·0262
		45	1·00	6·06	7·06	0·0206
	$BaCl_2$	25	0·52	0·132	0·652	0·0462
		35	0·50	0·100	0·600	0·0248
		45	0·48	0·092	0·572	0·0104
	$AlCl_3$	25	0·16	0·125	0·285	0·0240
		35	0·15	0·096	0·246	0·0185
		45	0·14	0·089	0·229	0·0086

DISCUSSION

The merit of the equation, $C=a+\frac{m.1/t}{n+1/t}$ remains unaffected by the temperature as revealed by the viscometric study of slow coagulation of ferric tellurate, chromium tellurate, ceric oxide, and vanadium pentaoxide sols at different temperatures. All the three constants are found to decrease with rise in temperature of the coagulating system. The decrease in the value of 'a' with the rise in temperature indicates that the value of maximum stability concentration causing no coagulation, is reached at lower concentration of electrolytes for each sol and less electrolyte becomes sufficient to start coagulation. The decrease in the value of 'm' suggests that a much smaller quantity of electrolyte at higher temperature causes instantaneous coagulation. Similarly the decrease in the value of 'n' with rise in temperature indicates a greater degree of aggregation taking place at higher temperature (Gann, loc. cit.). The decrease in the value of (a+m) indicates that the region of slow coagulation merges into that of rapid coagulation at lower concentration of electrolyte, i.e., the stability of sols decreases as temperature increases. This is in accordance with the observations of Garner and Lewis[18] and Burton and Deacon.[19]

The results obtained are in good agreement with the conclusion drawn from Freundlich's theory[20] of slow coagulation, which assumes that only those particles are coagulated whose kinetic energy is greater than the critical value. It is thus obvious that the rise in temperature would certainly increase the kinetic energy of the particles which would result in the coagulation of sol at a lower concentration of the coagulating ions. Consequently the values of the constants 'a', 'm' and 'n' of Bhattacharya's equation will also decrease. These results are also found consistent with the inferences which can be drawn from Ghosh and Gangopadhyay's theoretical derivation (loc. cit.), considering the temperature as a variable during the process.

Ghosh and Gangopadhyay (loc. cit.) have derived the equation from Reerink and Verwey and Overbeek's equations.[21] They have considered α, β and γ as constant terms having the values

$$\alpha = \frac{0{\cdot}85 \times 10^{-6}\, r\, \gamma^2}{kTz^2} \qquad \ldots(1)$$

$$\gamma = \frac{\exp.\left(\frac{ze\psi_0}{2kT}\right) - 1}{\exp.\left(\frac{ze\psi_0}{2kT}\right) + 1} \qquad \ldots(2)$$

$$\beta = (\alpha + \tfrac{1}{2}) \qquad \ldots(3)$$

Where r=particle radius, k=R/N, z=Valency,

e=electronic charge, N=Avogadro number,

T=temperature, ψ_0=surface potential of colloidal particles.

It has been further assumed in their final stage of derivation that 'a' and 'm' are

$$a = \frac{a_1\,(\beta - 1)}{\beta} \qquad \ldots(4)$$

$$\frac{1}{m} = K\, a_1.\,{}^{\beta-1}\;\beta \qquad \ldots(5)$$

Where a=critical stability concentration,

m=concentration above the critical value 'a' to cause instantaneous coagulation,

a_1=a constant near the concentration C of Bhattacharya's equation.

K=a constant term in Ghosh's equation (loc. cit.). On rewriting equation (4)

$$a = a_1\left(1 - \frac{1}{\beta}\right) \qquad \ldots(6)$$

From equation (1), (2) and (3) it becomes clear that on increasing temperature the value of β decreases. The coagulation concentration of electrolyte C of Bhattacharya's equation also decreases with rise in temperature, hence the constant a_1, which is very near the value of C, will decrease. Thus equation (6) shows the decrease in the value of 'a' with the rise in temperature.

Since a_1, in the equation (5) is a fraction and $\beta > 1$ as assumed by Ghosh (loc. cit.), the value of $(\alpha_1^{\beta-1} . \beta)$ will increase or 'm' will decrease with the rise in temperature.

Ghosh et al. (loc. cit.) have shown that 'n' may be taken as equal to 1/T, where T is the time taken for coagulation at a sufficiently high concentration of added electrolyte. According to Smoluchowski[22]

$$T = \frac{1}{8\pi D r n_0}.$$

and therefore

$$n = 8\pi D r n_0$$

n is the susceptibility of the sol to the electrolyte.

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Fig. 1. Coagulation of Ferric Tellurate Sol
at 20°C with KCl

I Conc. of KCl = 240 mM/l III Conc. of KCl = 215 mM/l
II Conc. of KCl = 230 mM/l IV Conc. of KCl = 200 mM/l

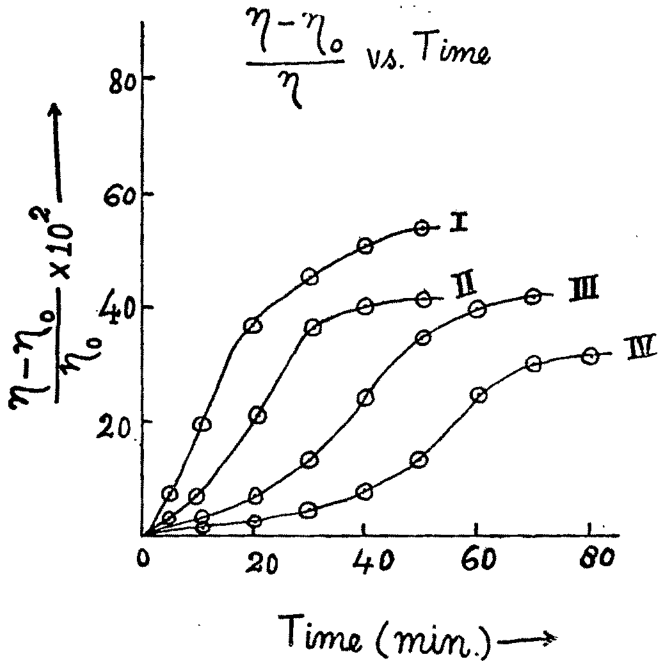


FIG. 2. Coagulation of Ferric Tellurate Sol at 20°C with KCl

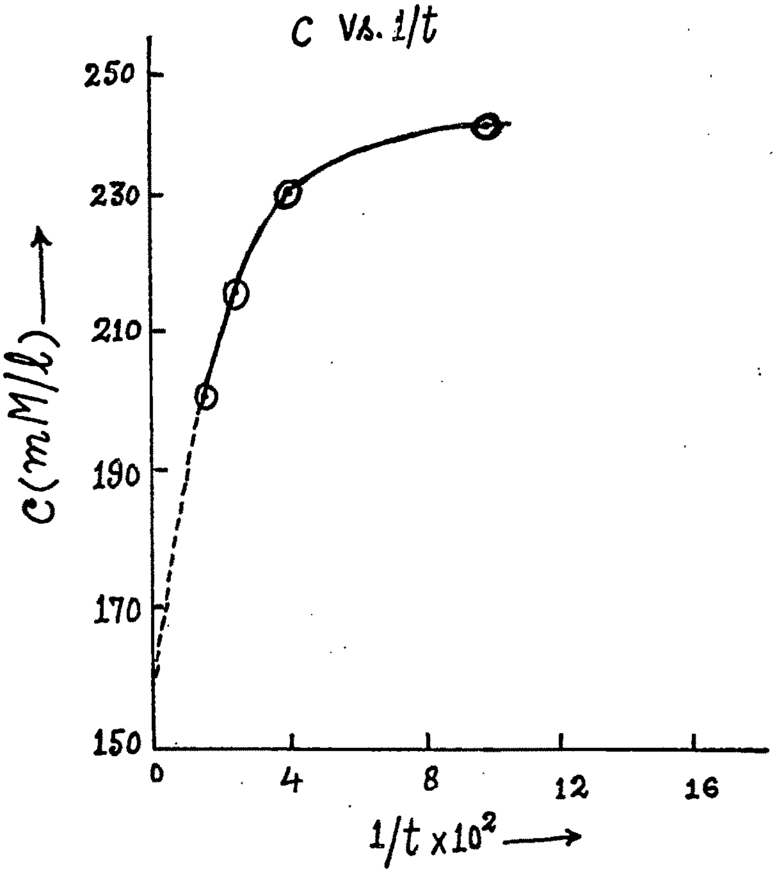
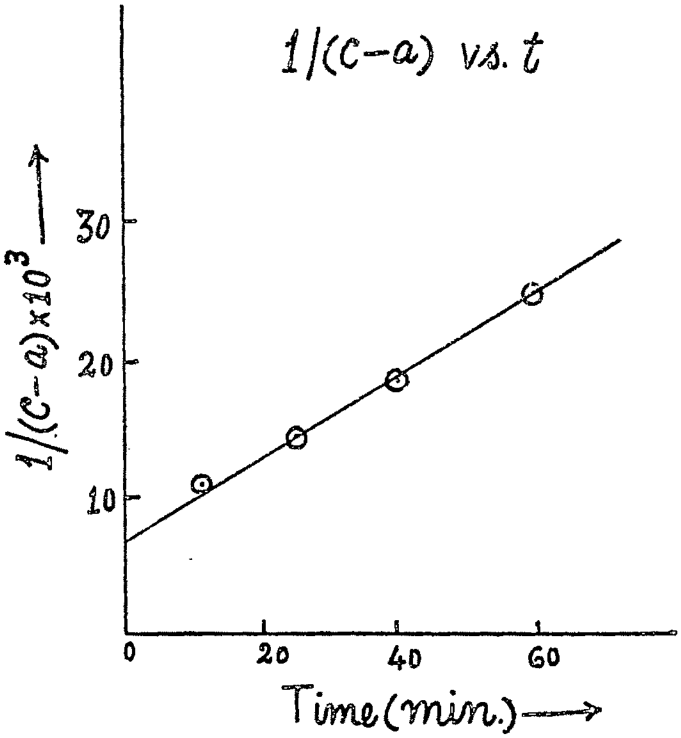


FIG. 3. Coagulation of Ferric Tellurate Sol at 20°C with KCl



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STUDIES ON DIACETYL PRODUCTION DURING SOURING OF MILK*

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One of the very desirable qualities of fermented dairy products is the flavour and aroma. This flavour and aroma of the product is considered to be mostly due to its diacetyl content. Diacetyl is not normally present in fresh milk or sweet cream.

It has been widely accepted that citric acid is the mother substance for production of diacetyl, though some workers also hold a view, that lactose can also be a source of diacetyl production. Even a low concentration is essential to impart a pleasing flavour to fermented milks.

In achieving a desirable flavour and aroma in fermented milks, the temperature and time of incubation, the bacterial quality of the milk and the type of starter all are almost equally important. Of the fermented milk products in which production of diacetyl is important are notable *dahi* and *lassi* under Indian conditions.

Amongst the products that are formed by the break down of citrate, diacetyl contributes directly to the flavour. Acetyl-methyl carbinol has also an important place, as it can be spontaneously oxidized to diacetyl. But 2, 3-butylene glycol has no value as it is an irreversibly reduced form and its formation is undesirable.

The production of diacetyl is influenced by a number of factors viz., pH, citrate content, redox potential, incubation temperature and storage conditions of cultures. Of these factors, the first three have a major importance.

Foreign workers Michaelian and Hammer (1936); Barnicoat (1937); Cox (1945); Evenhius (1951) and Coppens (1954) studied the effect of some of the factors on the diacetyl production. Systematic information available on diacetyl production under Indian conditions especially of Buffalo milk during its souring is completely lacking.

An attempt has been made in the present work to study the role of certain factors on the production of diacetyl during souring in Buffalo milk. The effect of following factors has been studied:—

1. Levels of acidity
   (·4, ·6, ·8, 1 present serum acidity)

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* Contribution No. A. H. & D. 109/R66/DS 22.

2. Addition of different concentration and forms of citrates at ·8 and 1% acidity. (viz., Citric acid, Sodium citrate)
3. Efficiency of different forms of citrates.
4. Effect of aeration at different intervals (i. e., after 2, 4, 6, 8, 10 and 12 hours of adding starter).

MATERIALS AND METHODS

Raw Buffalo milk was collected from the College dairy in a stainless steel container. The milk was heated to boiling with constant stirring and was immediately cooled to 70°F. It was then, distributed into 250 ml. beakers in lots of 230 c. c. in each beaker. Milk in each beaker was inoculated with 1 per cent starter and were incubated at 70°F. Acidity test was made periodically till the desired level of acidity was reached and the sample was taken up for estimation of diacetyl.

When citric acid or Sodium citrate was to be added, it was added in the form of soluble form just prior to inoculation with the starter. A control was also run simultaneously without the addition of citrates.

To study the effect of aeration, two identical sets of samples were taken —one set (the control) was not aerated at all while the other was aerated by stirring and incorporating air into it. After the predecided period for this treatment, the sample was left undisturbed. After these samples reached their proper acidity levels, were taken up for analysis. The diacetyl content was determined as recommended in A. P. H. A. (1955).

RESULTS AND DISCUSSION

1. *Effect of levels of acidity*

With the increase of acidity there is also an increase in the total diacetyl content. Pronounced increase in flavour and aroma was noticeable at higher acidities. From the figures in the last column of table 1 it can easily be seen that the highest rate of increase in diacetyl production is for the range 0·6-0·8% acidity while for higher acid range the rate of increase is comparatively very low. From this it seems that the optimum acidity for best production of the flavour lies between 0·6 and 0·8% while ripening to higher levels of acidity may be comparatively uneconomical from the point of view of flavour production.

Michalian (1938) and Barnicoat (1937) also showed that high acidity of the medium has a positive effect on the production of total diacetyl. Further, though, acetyl methyl carbinol (the precursor of diacetyl) may be produced at lower acidities, it does not directly contribute to flavour value till it is actually converted into diacetyl, because acetyl methyl carbinol is an odourless compound.

TABLE 1

Shows the effect of different levels of acidity on the production of total diacetyl content during souring of milk.

Acidity level (per cent)	Total diacetyl content Average (PPM.)	Rate of increase in diacetyl Production in m. gm./0·1% acidity.
0·4	13·70 (12·51—14·90)*	2·31
0·6	18·32 (16·37—20·26)	
0·8	44·36 (44·02—44·70)	13·02
1·0	48·42 (47·68—49·17)	2·03

* Figures in Parenthesis indicate Range.

2. *Effect of addition of different concentrations and forms of citrate*

At both levels of developed acidity the addition of both citric acid as well as Na citrate had favourable effect on the production of diacetyl with increasing concentrations of both forms of citrates (Table 2).

The data (in Table 2) show a somewhat analogous behaviour of the added citrates at both levels of developed acidity. The rates of increment are almost equal at all levels except at higher concentration of added Sodium citrate. Amounts beyond the level of 0·15% citric acid (as Sodium citrate), have little influence on the rate of increment in production of diacetyl, when sodium citrate was added the maximum production of diacetyl was obtained, upto 0·15 per cent citric acid (i. e., 0·272 per cent of added sodium citrate). Further confirmation is being planned to repeat the trials.

TABLE 2

Showing the effect of concentration of added citrate

Level of added citric acid	At 0·8 per cent acidity				At 1 per cent acidity			
	Production of Diacetyl due to addition of citric acid		Production of Diacetyl due to addition of Na citrate		Production of Diacetyl due to addition of citric acid		Production of Diacetyl due to addition of Na citrate	
	Production (PPM)	% Increase	Production	% * Increase	Production	% Increase	Production	% * Increase
0 (Control)	28·31	...	44·7	...	29·11	...	61·23	...
0·05%	30·54	7·8	47·08	5·0	38·74	33·0	65·40	6·8
0·10	35·61	25·7	50·06	11·9	42·01	44·3	70·47	15·0
0·15	37·69	33·1	57·36	28·3	45·29	55·3	80·90	32·1
0·20	39·48	39.4	59·74	33·6	49·91	71·4	81·05	32·3

* (Amounts of Na. citrate equivalent to the free citric acid level were added).

3. *Effect of efficiency of added citrate*

Addition of free citric acid resulted (Table 3) in a higher percentage increase in total diacetyl production and also at a higher rate of increment than the added trisodium salt of citric acid. At 0·15 per cent level: At both levels of souring the rate of increase in diacetyl production was higher with sodium citrate in comparison to free citric acid (Table 3).

TABLE 3

Showing the efficiency of added citrate in two different forms (citric acid and sodium citrate.)

Levels	Levels of acidity			
	0·8%		1%	
	Citric acid % increase	Sodium citrate % increase	Citric acid % increase	Sodium citrate % increase
0·05	7·8(1·56)*	5·0(1·0)	33·0(6·6)	6·8(1·36)
0·10	25·7(3·58)	11·9(1·38)	44·3(2·26)	15·0(1·64)
0·15	33·1(1·48)	28·3(3·28)	55·5(2·24)	32·1(3·42)
0·20	39·4(1·26)	33·6(1·06)	71·4(3·18)	32·3(0·04)

* (Figures in Parenthesis indicate actual increase in the production of Diacetyl in PPM.)

It is possible that citric acid being in free form contributes its own share of hydrogen forms and thus may have some effect on the pH, and causes the difference in the efficiency of diacetyl production between the two forms.

4. *Effect of aeration*

The mean ratio of the amount of diacetyl in the aerated samples to the corresponding non-aerated samples show a progressive increase from 1·074 to 2 hours upto nearly 4 times after 12 hours (Table 4). The apparent increase in the time may be paradoxical at the first glance. But actually the time factor is not of prime importance. Since it is just an indirect indicator of the developed acidity (i. e., the extent of souring), because with increase in time there is an increase in the amount of lactic acid produced. Thus it is obvious that aeration has greater beneficial effect at higher acidity. In addition to it, there is increase in rate of production at higher levels of acidity also (Tables 1 & 4). The acetyl methyl carbinol undergoes spontaneous oxidation to diacetyl under high redox potential. The main effect of aeration is apparently to aid the conversion of the synthised acetyl methyl carbinol into diacetyl, by increasing the existing oxidation reduction potential of the medium. The aeration would also help restoring the level of dissolved oxygen to a more favourable level for normal activity of organisms. It would also possibly prevent the degradation of acetyl methyl carbinol from becoming converted into the irreversibly reduced form of 2, 3-butylene-glycol which has absolutely no flavour value. The beneficial effect of aeration thus seems to act in more than one direction.

TABLE 4

Showing the effect of aeration at different intervals of time.

Time of aeration in hours	Acidity per cent	Amount of total diacetyl content PPM (Average figure)		Ratio between aerated and non-aerated samples
		Non-aerated (control)	Aerated	
2	0·18	4·17	4·48	1·074:1
4	0·25	4·76	9·24	1·94:1
6	0·36	13·86	33·32	2·4:1
8	0·47	16·54	42·32	2·55:1
10	0·52	19·07	57·96	3·03:1
12	0·56	21·60	85·29	3·94:1

SUMMARY AND CONCLUSION

The roles of major factors that affect diacetyl formation were studied:— different levels of acidity, and different concentrations and forms of citrate, and effect of aeration.

The rate of increase in diacetyl production was maximum in acidity level of 0·8-0·9 per cent, and no significant increase were observed at higher levels.

Both citric acid and sodium citrate had favourable effects on diacetyl production with increasing concentration.

The addition of free citric acid resulted in higher percentage increase in total diacetyl production and also at a higher rate of increment than the added tri-sodium salt of citric acid.

The aeration had favoured increase in production on total diacetyl.

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Abstract of Theses

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STUDIES ON ANTIGENICITY AND PATHOGENICITY OF SMOOTH AND ROUGH STRAINS OF *LISTERIA MONOCYTOGENES*[1]

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The present work "studies on antigenicity and pathogenicity of smooth and rough strains of *Listeria monocytogenes*" was undertaken in the search of an antigen which may be associated with pathogenicity. For this purpose, the morphological, biochemical and antigenic characters of the smooth as well as rough strains of *Listeria* were studied employing physico-chemicals and biological methods.

It was observed during the course of the work that *Listeria* strains, in smooth phase had a tendency to dissociate into the rough phase on storing at room temperature (18 to 25°C) for two weeks or more. It was further noticed that the dissociation in the smooth colonies started in the form of "filamentous outgrowths".

Descendent rough strains obtained from different serotypes of *Listeria*, showed better growth at low temperature, 25°C. But when attempts were made to grow rough strains at higher temperature, 45°C, an interesting point noted was that out of five strains, the growth of two rough strains was inhibited at the higher temperature. When rough strains were tested for the roughness with acriflavin (1:1000) and basic fuchsin (1:2000) tests, they were agglutinated with these dyes while the corresponding parent smooth strains were not affected. In addition to these tests of roughness it was also observed that when the rough strains of *Listeria* were heated with 1 per cent aqueous solution of 2,3,5, triphenyl-tetrazolium-chloride, agglutination of rough strains took place while the corresponding smooth strains remained uniformly suspended.

Preliminary characterization studies on the smooth and rough strains of *Listeria monocytogenes*, further revealed that the rough strains differed from the corresponding parent smooth forms in their colonial and cultural morphology but they were indistinguishable from the parent smooth forms on the basis of biochemical and fermentative reactions. However, some quantitative differences were recorded between smooth and rough strains of *Listeria* with respects to haemolysis, phospholipinase and catalase activities. Rough strains were weekly haemolytic; less phospholipinase and week catalase producers in comparison with the parent smooth strains. Besides the differences in the above activities it was also recorded that the rough strains of *Listeria* were more susceptible to the action of antibiotics and tetrazolium chloride than the respective parent smooth types.

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Studies on heat stable somatic antigens of smooth and rough strains revealed that rough strains of *Listeria* were antigenically similar to the corresponding parent smooth types with respect to distribution of heat stable somatic antigens. Agar-gel-precipitation test further revealed that a type specific precipitinogen may be present in the rough strains which is different from that in the parent smooth strains.

The chemical analysis carried out on *Listeria* strains indicated a marked difference in the composition of the smooth and rough strains. Total nitrogen, total phosphorus, total reducing sugar, total hexosamine, total uronic acid contents were more in the smooth strains than in the rough. Similarly, RNA and DNA contents were higher in the smooth strains than in the rough. On the basis of RNA contents, the smooth strains of the *Listeria* were divisible into two groups. The RNA/DNA ratio was higher in the rough strains. Chromatographic analysis of acid hydrolysate from whole cell of *Listeria* strains in smooth and rough phase revealed presence of 14 amino acids in all the strains. There was no difference in the distribution pattern of different amino acids in the smooth and rough strains. The relative concentration of glycine was more amongst the 14 amino acids. Similarly, chromatographic analysis did not reveal any difference in distribution of different sugars in the smooth and rough strains of *Listeria*. Chemical studies on the phenol and autoclave extracts of different strains of *Listeria* further revealed that smooth forms contained less carbohydrate and uronic acids in the extracts than the rough forms. On the other hand protein and DNA contents were more in the smooth forms than in the corresponding rough forms.

During the experimental *Listeria* infection in rabbits with smooth and rough strains an increase was noted in the total serum protein, serum hexose (glycoprotein), serum cholesterol and hexose: protein ratio. Paper electrophoretic studies showed a marked increase in α_2 and β globulins and a decrease in albumin. A lowered A/G (Albumin: globulin ratio) was also observed with the increase of duration after infection. In addition to alterations in serum components, it was also observed that with the increase of duration after infection there was increase in blood coagulation time and monocyte count. All these changes were less marked in the infection with the rough strains than in the case of the parent smooth strain although the dose of infection was the same in both the cases.

Immunisation studies with smooth and rough strains in sheep and rabbits further revealed that the formalized al-hydroxide-gel-vaccine of the smooth strain and rough culture al-hydroxide-gel-vaccine were protective in the rabbits. Trichloroacetic acid precipitated *Listeria* antigen from the smooth strains was a better allergen for testing skin sensitivity in listeriosis.

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CERTAIN PROBLEMS IN GRAVIMETRIC DEFLECTIONS OF THE VERTICAL[1]

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The thesis deals with certain problems that arise firstly while deciding the question of what reduction of the gravity anomalies best suits the determination of the gravimetric deflections of the vertical from the Vening Meinesz's formula, and secondly while carrying out condensation reductions according to Helmert's method or for condensation surface of any elevation as envisaged in the suggested modified Earth model free-air gravity anomaly in determining gravimetric deflections of the vertical. It is divided into seven Chapters.

The first Chapter is a short review of the relevant work done to-date on the subject of gravimetric deflections of the vertical and condensation reductions, and also the various problems in these connections. The works of Stokes, Vening Meinesz, Donald A. Rice, Sollin, Chuji Tsuboi, Molodenskii, Hunter, Lambert and Cassinis are briefly described. After giving a cursory account of the problems, mention has also been made of the motivation of the thesis.

The second Chapter introduces the subject of gravimetric deflections of the vertical with explanatory notes on the geoid, the reference ellipsoid and the relative and absolute deflections of the vertical which are indispensible in the present discussion.

The third Chapter contains a brief discussion of the principles of physical geodesy and the deduction of the Vening Meinesz's type formula for determining both the components of the deviation of the vertical. The existing method of working out the Vening Meinesz's formula is also briefly described.

The fourth Chapter deals with the reductions of various gravity anomalies which constitute the major factor in the evaluation of the Vening Meinesz's integral.

The fifth Chapter deals with the considered problems as detailed below:—

Gravimetric problems—In principle every gravity reduction that gives boundary values at the geoid is equally suited for the determination of the deflections of the vertical, provided the indirect effect is properly accounted for. Thus the selection of a good reduction method should be made from considerations of the simplicity of computations, the feasibility of interpolation between the gravity stations, the smallness or even absence of the indirect effect, etc. The Bouguer, isostatic, inversion and free-air reductions with the Helmert's condensation correction, have been examined and their merits and demerits considered in the light of the above considerations, and it has been concluded that the free-air reduction with the Helmert's condensation correction is the best. But as in all reduction methods, the gravity anomalies are subject not only to the uncertainty due to the use of the normal rate of change of gravity with elevation, but also involve knowledge of the density of the protruding matter above the surface of the geoid, which practically never can be attained.

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Recent investigators like Molodenskii, Hunter, etc. have developed entirely new theories which signify the abandonment of the geoid as an intermediate surface and emphasize the fact that the reference ellipsoid is not only a surface but a rotating solid body. It is also immediately clear that ground-level quantities, such as free-air gravity anomalies, are better suited for the computation of the effect of gravitational disturbances on space trajectories and satellite orbits than the corresponding quantities referred to the geoid which is separated from the external field by the outer masses. But then for practical quadratures, we need gravity anomaly values representative of the elementary area of quadrature from the point-values observed, which is not possible particularly in regions of rugged topography in the case of free-air anomalies being intractable for correct interpolation. Molodenskii has, however, made use of free-air anomalies alone in obtaining a general solution which is hypothesis-free but which must then make assumptions to a continuous field before a unique solution to the boundary problem can be achieved. Instead of actually doing away with the usual assumptions with regard to densities of the protruding matter above the quasi-geoid, Molodenskii has simply deferred them to a later stage which makes his solution considerably complicated. Moreover, the deflections of the vertical is greatly affected by Molodenskii's correction which in extreme case may attain values of a few seconds and thus makes it impossible to use Vening Meinesz's formula to free-air anomalies directly without taking into consideration the Molodenskii's elaborate correction. This has led Hunter to a concept of an Earth model with smoothered topography. However, the Earth model reduction formula as evolved by Hunter for reducing the observed values of gravity to the surface of the Earth model has been proved by the author to be not quite accurate, and has, subsequently, been reduced to a more simplified form. But all the same, the deflection values obtained need also an additional elaborate correction for reducing them from the Earth model to the actual earth, apart from the assumption of densities of the transferred matter being still there though in a much lesser degree than that actually involved in the Molodenskii's method of reduction. The problem, therefore, requires to be re-examined more closely with a view to evolving a new process of reduction in which the above difficulties are either considerably reduced or eliminated completely without sacrificing the standard of precision of the whole process.

Condensation reduction problem—The existing method of carrying out condensation of the protruding matter on the geoid as Helmert did or on the Hunter's Earth model as required in the suggested method of gravity reduction, is also defective in the sense that the required condensation correction is not possible to be computed to the desired degree of accuracy, either by means of Lambert's approximate formula or by the procedure given in the Cassinis' Fundamental Tables. In these circumstances, the above problem also requires to be re-examined more carefully with a view to developing a rigorous formula for a more precise solution, and providing relevant reduction tables easily adaptable for general use.

The sixth Chapter provides a new method of gravity reduction, namely, modified Earth model free-air gravity anomaly as an adequate solution to the first problem. At first the reduction method of Hunter's Earth model gravity anomaly is discussed in detail, and then by utilising Stokes's concept of condensation of protuberant matter in reducing the observed values of gravity on the actual earth to the level of Hunter's Earth model, a modified Earth model free-air gravity anomaly is derived. This does not lead to any sensible co-geoid as in other methods, and applies straight away in the Vening Meinesz's formula providing gravimetric deflections of the vertical right at the ground level without any further elaborate corrections as required in the Molodenskii's formula or in Hunter's Earth model reductions for conversion of the derived gravimetric deflections to the actual earth. The effects of the curvature, gravity and assumed crustal density errors are also amply minimised in the computational procedure followed. Moreover, the modified Earth model free-air gravity anomalies are useful for prospecting gravimetry as well as for near-satellite orbit study.

The last Chapter provides a rigorous formula for the precise determination of condensation reductions having condensation surfaces of any elevations including those of the geoid and the Earth model. The formula has been developed on the basis of spherical hypothesis for the mathematical form of the earth, and the relevant fundamental or special tables of condensation reduction derived therefrom are easily adaptable for general use.

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STUDIES ON HAEMAGGLUTINATION AND PROPAGATION OF FOOT-AND-MOUTH DISEASE VIRUS IN TISSUE CULTURE[1]

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This study was undertaken to evolve a simple diagnostic test of Foot-and-Mouth disease and to adapt, propagate and observe the cytopathic changes caused by Foot-and-Mouth disease virus in lamb kidney and lamb testicle cell monolayer cultures.

Haemagglutination test which is a simple and easy procedure to diagnose certain viruses, was extensively investigated, during present study. Erythrocytes from 38 different vertebrate species viz., 18 mammals, 16 avians, 2 reptiles and 2 amphibians were tested at 4°C and 37°C, 6 and 7 pH levels using citrate buffered saline and phosphate buffered saline as diluents. None of the standard types viz., O; A, C, and Asia 1 of Foot-and-Mouth disease virus gave specific haemagglutination reaction with the erythrocytes of various species screened. However, certain non-specific reactions with erythrocytes of goat, rabbit, guinea-pig, wild rat, albino rat, mole, squirrel, fowl, little egret, scops owl, and Indian Robin were observed. Erythrocytes from sheep, pig, donkey, camel, buffalo, cow, dog, bat, wild mouse, albino mouse, Myna, Chhoti Myna, sparrow, crow, pigeon, dove, babbler, parrot, white scavenger vulture, hoopoe, blue Jay, Saras crane, garden lizard, tortoise, toad and frog gave no haemagglutination reaction.

A field strain of Foot-and-Mouth disease virus was isolated from a natural case in a cow, which was found to be typed O by complement fixation test after inoculating in unweaned suckling mice where it caused 100% mortality preceded by usual symptoms of paralysis of hind limbs and respiratory distress.

Lamb kidney and testicle cell monolayer cultures were prepared from organs of young healthy lambs 6-10 weeks of age. Hank's B.S.S. with 0·5% Lactalbumin hydrolysate, 0·05% yeast extract and 10% inactivated calf serum was used as growth media. Trypsin dispersed, renal cortical cells in concentration of 1:100 (in growth medium) and testicle cells in concentration of 1:150 (in growth medium) were put in tubes kept slanting. In case of kidney cells medium was changed every 4-5 days whereas in case of testicle cells every 48 hours. Kidney cells formed complete monolayer in 8-10 days and testicle cells in 4-5 days and the change was then made to maintenance medium which contained no serum. Inactivated pooled cow calf sera in growth media were found to give better results.

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[1] This is an abstract of the thesis submitted to Agra University in partial fulfilment of M.V.Sc. degree of 1967.

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Newly isolated type O Foot-and-Mouth disease virus was inoculated in monolayers to study its adaptation, propagation and cytopathogenic effects. Ten serial passages in lamb kidney cell cultures were conducted. Five serial passages were carried in lamb testicle cell cultures using 5th passage virus from lamb kidney cell monolayers. Titration of virus material at 5th and 10th passage levels in lamb kidney cell monolayers and a titre of 10^7 and 10^8 respectively was recorded. Virus material from 5th passage in lamb kidney cell monolayers was also titrated in suckling unweaned mice and a titre of 10^6 recorded. Titration of virus material at 5th passage level in lamb testicle cell cultures was carried in lamb kidney cell monolayers and a titre of 10^5 recorded.

The confirmation of field strain type was further made by serum-neutralization test in tissue culture. The cytopathic changes were specifically inhibited by hyperimmune type O serum having no such effect with hyperimmune sera against other types.

Using this strain in lamb kidney cell monolayers, cytopathic changes in cells were observed. Reduction in mitotic figures, clumping of nuclei forming cell aggregates, cytoplasmic prolongations, nuclear and cytoplasmic degenerative changes leading to lysis of the cells were well defined. Cytopathic effects were noticed as early as four hours after virus adsorption and within 24 hours complete disruption of cell sheet was evident.

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STUDIES ON
THE PATHOLOGY OF MAMMARY GLANDS OF BUFFALOES*

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ABSTRACT

The pathology of the mammary glands of buffaloes has been taken as subject of study to elucidate the present day knowledge on the aetiology, nature, and extent of pathological conditions encountered in the mammary glands of apparently healthy buffaloes slaughtered for meat at Tangra(Calcutta) and Bareilly slaughter houses. 6800 female buffaloes were screened, and 325 samples of quarters were collected from 300 animals. Of these 325 samples, 164 were found normal and the rest 161 showed gross and microscopic abnormalities. The account of pathological entities are given briefly in the following table:—

Sl. No.	Name of Pathological conditions encountered	No. of quarters	Percentage
1.	Fatty changes	1	0·62 per cent
2.	Haemosiderosis	1	0·62 ,,
.	Haemorrhages	7	4·35 ,,
4.	Involution	23	14·28 ,,
5.	Hyperplasia	2	1·24 ,,
6.	Metaplasia	40	24·84 ,,
	A. Squamous type		
	(a) With organisms	22	13·66 ,,
	(b) Without organisms	18	11·18 ,,
	B. Cartilagenous type	1	0·62 ,,
7.	Cisternal papilloma	1	0·62 ,,
8.	'Comedo' carcinoma	1	0·62 ,,
9.	Tuberculous mastitis	1	0·62 ,,
10.	*Fusiformis necrophorous* mastitis	1	0·62 ,,
11.	Streptococcal mastitis	28	17·39 ,,
12.	Staphylococcal mastitis	12	7·46 ,,
13.	Corynebacterial mastitis	30	18·64 ,,
14.	Mixed infection causing mastitis	1	0·62 ,,
15.	Chronic mastitis	32	19·88 ,,
16.	Mycotic mastitis	2	1·24
	Total	161	100·00 ,,

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* This is an abstract of the thesis submitted to and approved by the Agra University, for the award of of M. V. Sc. degree in Pathology under supervision of Sri P. K. R. Iyer.

One case of diffuse fatty changes of the quarter with r grandular tissue by areas of fat was detected. The parenchyma s chronic change.

One quarter revealed changes associated with haemosiderosis intra-cytoplasmic but extra nuclear deposition of haemosiderin pigme the lining cells of acini, duct and within the macrophages.

Haemorrhagic lesions, which were either focal or diffuse in nature seen in 7 quarters, occasionally replacing the glandular elements with large areas of haemorrhages. 23 quarters showed changes associated with involution. The lesions were characterised by atrophy of acini and an increase of stromal tissues resulting in involution of the gland.

Two quarters manifested hyperplastic proliferation of ductal and alveolar lining cells and these resembled the lesion of epitheliosis.

Forty quarters showed metaplastic changes of the lining cells of the ducts. Of these 22 were associated with various micro-organisms. The ductal lining cells showed squamous metaplastic changes together with keratinisation and pseudoepitheliomatous hyperplasia. The latter changes were found in 10 quarters. In one quarter, metaplastic transformation of periductal connective tissue into cartilage was observed in association with Streptococci.

One quarter showed lesions of papilloma arising from the milk in cistern which macroscopically were 2-3 mm. in height and almost filling the lumen of the cistern. A single case of intraductal carcinoma of Camedo type was identified. The growths were in the nature of solid alveolar pattern with a central zone of necrosis originating from small, medium and large sized ducts.

One quarter revealed chronic nodular type of tuberculous mastitis involving most of the lobules without any involvement of peri-lobular connective tissue. One quarter showed necrotising lesions together with a large number of organisms morphologically indistinguishable from *Fusiformis necrophorus.*

28 quarters showed acute, subacute, and/or chronic lesions associated with Streptococcal organisms in the sections. The lesion in acute types, in general were necrotic and suppurative type which ultimately progressed into chronic type. The ducts were universally involved and showed hyperplasia or occasionally squamous metaplasia of the lining cells. The surviving parenchyma revealed pressure atrophy. 12 quarters revealed changes associated with Staphylococci in the sections of these 6 revealed acute changes with diffuse areas of necrosis and suppurations. One of the quarters showed typical lesions of botromycosis. Other quarters showed changes varying from subacute suppurative to chronic type.

32 quarters revealed changes associated with Corynebacterial organisms in the sections. Acute lesions were observed in 7 and in the rest were chronic type. The lesions were those of suppurative nature and galactogenous in origin which progressed into the chronic type. One quarter also revealed

acute changes with a number of gram positive rod shaped and coccal organisms. 32 quarters revealed gross and histological lesions of chronic type without the presence of any pathogenic organisms of significance.

Two quarters showed lesions of acute mastitis with evidence of yeast like organisms in the lumen of acini.

Of the pathological entities described, haemosiderosis, intraductal carcinoma and tuberculosis in the mammary glands of buffaloes have been identified and described for the first time.